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PROJECTS INVESTIGATING OIL RECOVERY FROM NATURALLY FRACTURED RESERVOIRS

U.S. Department of Energy

National Petroleum Technology Office

January 1998

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Introduction

U.S. Department of Energy National Oil Program

The United States is dependent on oil and gas for approximately 65% of the energy it consumes. The Energy Information Administration 1997 Annual Energy Outlook projects increasing demand for oil and gas to 2015, and others forecast continuing dependence on these energy sources well into the next century. In recognition of these forecasts, the broad goal of the Department of Energy's National Oil Program is to ensure that reliable, competitively priced oil is available to support a strong U.S. economy while protecting the environment and providing energy security through the 21st century.

Significant U.S. oil resources remain, but they are becoming more difficult and expensive to discover and produce. It is estimated that as much as 351 billion barrels can be recovered from known reservoirs and an additional 25-60 billion barrels remain to be discovered. The DOE's National Petroleum Technology Office (NPTO), in partnership with universities, state and local governments, industry, national laboratories, and other stakeholders, is supporting significant research to develop and implement technologies to enhance the efficiency and environmental quality of domestic oil and exploration, recovery, and processing. By reducing costs, such advanced technologies can help to maintain reliable domestic supplies of these vital fuels at competitive prices—a goal of strategic importance to our Nation.

The National Oil Program research effort is divided into six product lines: Advanced Diagnostics and Imaging; Drilling, Completion, and Stimulation; Environmental; Processing and Refining; Reservoir Life Extension and Management; and Crosscutting Areas, which are multi-disciplinary in nature, "cutting across" the various product lines. Projects discussed in this document fall in two product lines: Advanced Diagnostics and Imaging, and Reservoir Life Extension and Management.

Advanced Diagnostics and Imaging:

To enable continued access to valuable U.S. energy resources, NPTO is committed to improving the cost effectiveness and efficiency of oil and gas exploration and production. The Advanced Diagnostics and Imaging Systems Program's specific role in this endeavor is threefold: to support the research, development, demonstration, and use of advanced imaging technologies in partnership with industry; to preserve and provide access to subsurface data; and to develop analytical tools to more accurately quantify oil and gas resources and reserves.

NPTO's support of RD&D is essential to achieving continued improvements in diagnostics and imaging technologies and to realizing the enhanced oil and gas production that these technologies promise. The RD&D resources of smaller producers, which account for a significant portion of U.S. oil and gas production, are particularly limited. These operators need reservoir characterization and extraction technologies to maintain and increase production. Without the impartial information and advanced technologies provided by NPTO, including costly modeling software, much of the more complicated domestic production would not occur.

By 2010, DOE and industry partnerships will yield:

- Increased discoveries of new domestic oil and gas fields
- Increased reserve growth rate of existing fields
- Increased volume of "booked reserves" per new wells
- Increased use of advanced seismic imaging to define drilling locations
- Increased use of advanced logging and wellbore geophysics for field development
- Increased availability and use of subsurface geologic data

The Advanced Diagnostics and Imaging Systems Program expects by 2010 to contribute 100 million barrels per year of additional oil production and a cumulative addition of 1.6 billion barrels in oil reserves.

Reservoir Life Extension and Management:

The goal of NPTO's Reservoir Life Extension and Management Program is to slow the rate of abandonment of commercially marginal oil and gas reservoirs by accelerating the development and transfer to industry of innovative, cost-effective technologies.

The Reservoir Life Extension Program supports research and development of promising technologies in areas identified as priorities by the domestic oil and gas industry. Some of this research taps the unique strengths of the National Laboratories, which focus on high-risk technology developments, where long-term payoffs are likely to prevent private companies from investing adequately on their own.

By 2010, DOE and industry partnerships will yield:

- Stabilization of the rate of oil and gas well abandonments
- Matching or exceeding the historical rate of enhanced oil recovery by the year 2000
- Arrested overall decline in oil production by the year 2000
- Increased use of program products by industry, particularly by independent oil and gas producers
- Increased participation of oil and gas producers in technology transfer seminars and topical workshops

These Reservoir Life Extension and Management technologies, if widely applied by the Nation's oil and gas producers, are estimated by DOE to be capable of increasing the annual yield of tertiary oil up to 1.9 billion barrels by the year 2015.

The following table lists projects funded by NPTO addressing production and exploration problems with naturally fractured reservoirs. The first projects listed are part of the Fundamental Geoscience Program; other projects are included from a variety of program areas mentioned previously. The fact sheets for this latter group of projects are arranged in alphabetical order by organization.

National Petroleum Technology Office
Projects Investigating Oil Recovery from Naturally Fractured Reservoirs

Fundamental Geoscience for Reservoir Characterization

Organization	Project Title/ Contract #	Project Description	Principal Technologies/ Methods
Alabama Geological Survey	Area Balance and Strain in an Extensional Fault System: Strategies for Improved Oil Recovery in Fractured Chalk, Gilbertown Field, Southwestern Alabama G4S51733	Demonstrate the utility of area balancing techniques in designing improved recovery programs for fractured oil reservoirs.	Use basic geologic methods, petrologic and geophysical methods, advanced structure modeling, subsidence and thermal modeling, and production analysis.
Bureau of Economic Geology, University of Texas at Austin	Using Microstructure Observation to Quantify Fracture Properties and Improve Reservoir Simulation G4S51732	Develop and verify a new approach for 1) quantifying the occurrence of open fractures and fracture-controlled permeability anisotropy in clastic oil reservoirs using microfracture information and 2) incorporating such characterizations in fractured-reservoir simulators.	Geostatistics, fractal analysis, scanning electron microscopy, cathode luminescence.
Golder Associates	Fractured Reservoir Discrete Fracture Network Technologies G4S51728	Develop a reservoir fracture model that can be used to implement thermally assisted gravity segregated (TAGS) recovery process. Hierarchical fracture models are being developed to quantify the distribution and flow characteristics of reservoir fractures.	Discrete fracture network modeling to evaluate pressures, flows, and connectivities of fractured reservoirs. Neural net technology.
Science Applications Int'l Corp.	Naturally Fractured Reservoirs: Optimized E&P Strategies Using a Reaction-Transport-Mechanical Simulator in an Integrated Approach G4S51730	Integrate advanced geoscience techniques with reservoir engineering concepts to optimize exploration and production strategies for naturally fractured oil reservoirs.	Reaction-transport-mechanical modeling combines geochemistry and geomechanics with geologic and production data. Remote sensing.
Southwest Research Institute	Characterization of Fracture Reservoirs Using Static and Dynamic Data: From Sonic and 3D Seismic to Permeability Distribution G4S51731	Map permeability anisotropy and other petrophysical parameters to understand reservoir fracture systems and associated fluid dynamics using acoustic logging and 3-D seismic techniques.	Acoustic logging, 3D-seismic measurement, and analytical solutions for plane-harmonic seismic wave propagation.

Organization	Project Title/ Contract #	Project Description	Principal Technologies/ Methods
TerraTek	Research and Development of Advanced Fracture Modeling in the Uinta Basin for Optimized Primary and Secondary Recovery G4S51729	Integrate surface investigations with subsurface data in a pronounced fracture system.	Surface geochemistry, remote sensing, geostatistics, fractal analysis, dual porosity fluid flow systems.
University of Utah	Characterization and Simulation of an Exhumed Fractured Petroleum Reservoir G4S51734	Develop predictive models of fault and fracture distributions, geometrics, and fluid flow characteristics using data from an exhumed fractured petroleum reservoir.	Fractured reservoir simulator, image analysis.

Other Projects in Fractured Reservoirs

Sandia National Lab	Geomechanics for Reservoir Management FEW 4365	Develop improved understanding and tools for reservoir management.	Fracture analysis at several field sites. Velocity-anisotropy tests to develop in- situ stress data. Reservoir rock characterization under 3-D stress states. Numerical techniques (Discrete Element Methods) to model geomaterials at the microscale.
Keener Oil & Gas Company	Telluric Surveys—Research & Development to Provide Resolutions to Producibility Problems G4P51722	Test the capability of tellurics as a tool to define subsurface features.	Drill horizontal well in Wilcox sandstone and test accuracy of electrotelluric signals to locate and define subsurface structures.
Utah Geological Survey	Increased Oil Production and Reserves from Improved Completion Techniques in the Bluebell Field (Class I) DE-FC22-93BC14953	Develop a multidisciplinary reservoir characterization approach to overcome low recovery caused by poor completion practices in fractured, clayey reservoirs in the Bluebell Field, Uinta Basin.	Correlation and mapping of well data, correlation of fracture patterns, borehole-imaging. Logging and re-completion using acid stimulation.
Los Alamos National Lab	Advanced Seismic Geodiagnostics-Borehole Acoustic Source/ Instrumentation for Fracture Mapping FEW A053	Develop new downhole measurement capabilities and analytical methods for processing and interpreting microseismic events.	Through-tubing 1-11/16 in. OD, 2-level geophone package designed and prototyped under CRADA with Schlumberger Wireline Services.

Organization	Project Title/ Contract #	Project Description	Principal Technologies/ Methods
Reservoir Engineering Research Institute	Fractured Petroleum Reservoirs DE-FG22-96BC14850	Develop an understanding of the role of diffusive, capillary, gravity, and viscous forces in the flow of fluids in fractured porous media.	Theoretical and experimental studies of 1) fracture capillary pressure and relative permeability, 2) new phase formation and flow in porous media, 3) water injection in fractured and layered porous media, 4) fracture reservoir characterization from PVT data.
BDM-Oklahoma, Inc.	Geoscience Research—Advanced Heterogeneity Characterization 95-A01 Task 05	Improve means for predicting production from fractured reservoirs and recommend improved production strategies. Use laboratory measurements to improve modeling and simulating production.	Mathematical modeling: Imbibition measurements on water-wet rocks used to refine simulation model. Model predicts oil production during spontaneous brine imbibition into reservoir rock.
Chevron USA Inc. Production Company	Advanced Reservoir Characterization in the Antelope Shale to Establish the Viability of CO_2-Enhanced Oil Recovery in California's Monterey Formation Siliceous Shales (Class III) DE-FC22-95BC14938	Increase oil recovery from the Monterey/Antelope Siliceous Shale through the application of an innovative reservoir management plan.	Advanced reservoir characterization including core analysis, well logs, crosswell seismic analysis, and outcrop analysis. Data incorporated into a comprehensive reservoir model.
Los Alamos National Lab	Fracture Mapping and Slimhole Geophone Array (PARTNERSHIP) P-10	Demonstrate applications using induced microearthquakes to map stimulation and natural fractures and fluid flow in oil reservoirs.	Downhole, 3-component geophone tools used to detect and map production-induced reservoir microearthquakes.
NM Institute of Mining & Tech	Improved Efficiency of Miscible CO_2 Floods and Enhanced Prospects for CO_2 Flooding Heterogeneous Reservoirs DE-FG22-97BC15047	Improve the effectiveness of CO_2 flooding in heterogeneous reservoirs.	1) Selective mobility reduction in foam flooding, 2) flooding at slightly reduced CO_2 pressures, and 3) using gravitational forces during low IFT, CO_2 flooding.
BDM-Oklahoma, Inc.	Geoscience Research—Heterogeneity Characterization 97-A01 Task 05	Characterize naturally fractured reservoirs and describe relationships that control fluid mobility and oil recovery in fractured rock.	Multiphase flow in fractures, imbibition process simulation in field-size heterogeneous matrix blocks. Upscale media properties using Wavelet analysis and renormalization.

Organization	Project Title/ Contract #	Project Description	Principal Technologies/ Methods
Parker & Parsley Development	Advanced Reservoir Characterization and Evaluation of CO_2-Gravity Drainage in the Naturally Fractured Spraberry Reservoir (Class III) DE-FC22-95BC14942	Determine the technical and economic feasibility of continuous CO_2 injection in the naturally fractured reservoirs of the Spraberry Trend.	Interaction of low-permeability rock matrix with fracture system in presence of CO_2 to produce oil via gravity drainage. Reservoir modeling studies. Drill a horizontal well to evaluate reservoir rock and fractures.
Sandia National Lab	Geomechanics of Horizontally Drilled, Stress-Sensitive, Naturally Fractured Reservoirs (PARTNERSHIP) FEW 2836.400	Determine the effects of rock properties, in-situ stresses, and changes in effective stress on the performance of horizontal wells in some stress-sensitive, naturally fractured reservoirs.	Cooperative project with Oryx. Field work, lab studies, experimental test techniques, and analytical models used in integrated geometrics study of Austin Chalk.
Reservoir Engineering Research Institute	Research on Fractured Petroleum Reservoirs DE-AC22-93BC14875	Develop a full understanding of the role of diffusive, capillary, gravity, and viscous forces in the flow of fluids in fractured porous media.	1) Miscible displacement, 2) critical gas saturation, 3) immiscible gas-oil gravity drainage, 4) water injection in fractured/ layered porous media.
BDM-Oklahoma BDM Petroleum Technologies	Geoscience Research--Heterogeneity Characterization 98-A01 Task 05	Determine the relationship among capillary pressure in fractures and fracture characteristics. Also the distribution and role of capillary pressure in controlling fluid mobility and oil recovery mechanisms in fractured rock.	Imbibition experiments on water-wet rock to refine imbibition simulation model. Apply model to other fractured rock scenarios.
K&A Energy Consultants Inc.	Simulation Studies to Evaluate the Effect of Fracture Closure in the Performance of Naturally Fractured Reservoirs DE-AC22-90BC14654	Use dual porosity simulator to evaluate reservoir conditions that reduce oil or gas recovery as a result of fracture closure. Investigate improved recovery by maintaining pressure support within the reservoir by fluid injection techniques.	Numerical simulation studies using TRIAD, a 3-dimensional, 3-phase, dual porosity simulator developed by K&A.
Lawrence Livermore National Lab	Reservoir Characterization of the Monterey Shale FEW 0001	Compile accurate geological, reservoir, and producing characteristics of California's Monterey Shale and recommend specific EOR processes for testing.	Review and analyze geological, reservoir, and production data. Model data using STARS to recommend EOR processes.

Organization	Project Title/ Contract #	Project Description	Principal Technologies/ Methods
Los Alamos National Lab	Mapping Conductivity Fractures Using a Through-Tubing Deployed Geophone Array FEW 9197	Evaluate the use of microseismicity induced through production, injection, and stimulation to determine the location of conductive fractures. Develop monitoring tool.	Through-tubing single geophone demonstrated in Prudhoe Bay Field. Designed and fabricated two sonde array. Multiple geophone arrays used in shallow wells.
University of Kansas	Advanced Recovery Concepts—In-Situ Permeability Modification Using Gelled Polymer Systems G4S60331	Develop and improve the application of gelled polymer technology for in-situ permeability modification.	Gelled polymers in model of fractured porous medium. Gel performance in carbonate rock. Develop gel systems for use with CO_2. Gel treatment in production wells.
BDM-Oklahoma BDM Petroleum Technologies	Geoscience Research—Imaging Technology 98-A01 Task 03	Develop, apply, and refine cross-cutting imaging techniques and technologies to study fundamental processes in oil recovery.	CT scan, automated minipermeameter, and computer-assisted petrographic image analysis.
NM Institute of Mining & Tech	Improved Efficiency of Miscible CO_2 Floods and Enhanced Prospects for CO_2 Flooding Heterogeneous Reservoirs DE-FG22-94BC14977	Improve the effectiveness of CO_2 flooding in heterogeneous reservoirs.	1) Selective mobility reduction in foam flooding, 2) flooding at slightly reduced CO_2 pressures, and 3) using gravitational forces during low IFT, CO_2 flooding.
Stanford University	Prediction of Gas Injection Performance for Heterogeneous Reservoirs DE-FG22-96BC14851	Develop design techniques for gas injection in a variety of different reservoir types.	Pore level model to predict transport parameters for 3-phase flow; develop fast reservoir simulator; 3-phase relative permeability and oil recovery for different systems.
Pan Western Energy Corp.	Aid to Independents G4P60384	Extend the wellbore of the Mayer #3 well horizontally 500 to 800 ft. to tap into vertical fracturing system.	Short radius extension system that permits the turn from vertical to horizontal to be made inside conventional 4 1/2 in. and 5 1/2 in. casing within 50 vertical feet.
Prairie View A&M	Theoretical and Experimental Study of Multiphase Flow in Fractured Reservoirs G4S60336	Apply theoretical and experimental techniques to the problem of multiphase flow and transport through fractured reservoirs.	Lab experiments and numerical modeling to represent multicomponent, multiphase mass transfer from porous matrix to fractures. New simulation model developed.

Organization	Project Title/ Contract #	Project Description	Principal Technologies/ Methods
Los Alamos National Lab	Characterization of a Fractured Dolomite Reservoir in Preparation for Water Flooding (PARTNERSHIP) FEW PG12	Evaluate seismic mapping technologies developed by LANL for optimizing the design of waterfloods in fractured oil reservoirs.	Single 3-component downhole geophone used to monitor microseismicity during waterflood and late primary production.
Reservoir Engineering Research Institute	Research on Fractured Petroleum Reservoirs DE-AC22-91BC14835	Quantify the physics of multiphase flow in fractured porous media.	Miscible fluid system studies and model development (1-D). Viscous flooding studies and model development. Water injection on Austin Chalk.
Sandia National Lab	Fractures and Stresses in Bone Spring Sandstones (PARTNERSHIP) FEW 2266.100	Determine whether natural fractures exist in and affect production from the Second Sandstone of the Bone Spring Formation, Delaware Basin, SE New Mexico.	Work with Harvey E. Yates Co. (Heyco), Roswell, NM, to conduct detailed core, log, geologic, and stress and well test activities on Heyco wells.
National Academy of Sciences	The Study of Fracture Characterization and Fluid Flow DE-FG22-91BC14837	Review, synthesize, and integrate current research and provide guidance for field application for characterization of fracture networks and fluid flow in rock fractures.	Committee of 12 experts convened to conduct study. Report published 12/94.
Sierra Energy Company	Enhanced Oil Recovery Utilizing High-Angle Wells in the Frontier Formation, Badger Basin Field, Park County, Wyoming (Class I) DE-FC22-93BC14950	Conduct study of Frontier Formation to assess feasibility of increasing recovery by drilling slant and horizontal wells to intersect oil-bearing fractures.	3-D seismic and core data to analyze the diagenetic history, rock properties, and the natural fracture system.
Stanford University	Scale-Up of Miscible Processes for Heterogeneous Reservoirs DE-FG22-92BC14852	Develop design techniques for miscible and near-miscible gas injection processes in heterogeneous fluvial deltaic (Class I) and carbonate (Class II) reservoirs.	New streamline simulation technique; calculation of minimum miscibility pressure in multi-component systems; 3-D flow; quantitative scaling estimates for transitions from capillary-dominated to gravity-dominated to viscous-dominated flow.

Organization	Project Title/ Contract #	Project Description	Principal Technologies/ Methods
BDM-Oklahoma	Improved Oil Recovery (Heavy Oil)–Core and Log Analysis from NPR #1 AC/15054 Task 08	Evaluate the 29R reservoir to determine technically feasible and economic methods of recovery that minimize bypassed and trapped oil.	Core analysis using CT scan and correlation of core-based petrophysical data and log data.
University of Southern California	Modification of Chemical and Physical Factors in Steamfloods to Increase Heavy Oil Recovery DE-FG22-96BC14994/SUB	Use simulation and visualization experiments to research methods to improve heavy oil recovery.	Study pore-network simulation and visualization of steam injection in fractured media.
Associated Western Univ.	Assist Graduate Student in Energy-Related Research for DOE 75-97SW41271	Better define the relationship between stratigraphy and fractured reservoir geometry in the Lindrith Field area.	NA

Fundamental Geoscience for Reservoir Characterization

The U.S. Department of Energy's National Petroleum Technology Office issued a Program Research and Development Announcement in 1996 requesting proposals that contained aspects of fundamental and applied research that integrate advanced geoscience and reservoir engineering concepts. The focus of the program is to quantify reservoir architecture, dynamics of fluid-rock and fluid-fluid interactions related to lithologic characterization, and impacts on producibility. Research methods require the acquisition and integration of characterization data from a wide variety of scales and the quantitative development of interrelationships based on scale definition as it relates to oil reservoirs. Interdisciplinary efforts focus on increasing well-to-well predictability for improving recovery efficiency from geologic formations containing known oil reservoirs, and πincorporating data from outcrop (mesoscopic) to core and pore (microscopic) scales.

Seven research contracts were awarded for fractured reservoir characterization and modeling research in 1996. The two- to three-year projects will study the relationship of geologic stress and local fracture patterns to regional tectonic systems and develop techniques to use this information to predict petroleum recovery.

Recipients are the Alabama Geological Survey, Golder Associates, Science Applications International Corporation, Southwest Research Institute, TerraTek, the Bureau of Economic Geology at the University of Texas at Austin, and the University of Utah.

These ongoing projects are described more fully in the following pages. DOE estimates that reserves in fractured reservoirs will increase by 32 million barrels within 11 years as a result of this research.

Project Title

Area Balance and Strain in an Extensional Fault System: Strategies for Improved Oil Recovery in Fractured Chalk, Gilbertown Field, SW Alabama

Partner

Alabama Geological Survey

Project Location

Alabama, Choctaw County

Project Formations

Selma Chalk, Eutaw Formation

Problem

Oil production in the Gilbertown Field has declined markedly since its peak production in 1951. Knowledge of the distribution of fractures is essential for designing improved recovery operations and maintaining continued operation of this marginally economic oil field.

Objectives

Analyze the geologic structure and burial history of Mesozoic and Tertiary strata in Gilbertown Field and adjacent areas to understand the relationship of strain to production in Gilbertown reservoirs, and to identify methods to improve oil recovery from these reservoirs.

Project Description

The Geological Survey of Alabama is compiling data on the fractures in the Selma Chalk and Eutaw Formation to enable producers to identify the best improved recovery methods for Gilbertown Field. Key technical advancements being sought include understanding the relationship of requisite strain to production in Gilbertown reservoirs, incorporation of synsedimentary growth factors into models of area balance, quantification of the relationship between requisite strain and bed curvature, determination of the timing of hydrocarbon generation, and identification of the avenues and mechanisms of fluid transport. Analyses of core samples and well logs are providing information on rock composition, oil and gas saturation, and other critical parameters. Structural and stratigraphic maps and cross sections derived from surface and subsurface data will document the distribution of strain in the Gilbertown fault system and its effect on fracturing. The impact of fracturing on the distribution and producibility of oil from extensional fault systems in Gilbertown Field and adjacent areas is being determined. Computer modeling of these geologic data and well performance characteristics is providing understanding of the influence of regional tectonics on local oil production and allowing producers to identify where improving operations will be most beneficial. Results from the project will be disseminated to regional operators by the survey's Petroleum Technology Transfer Center in Tuscaloosa through workshops, presentations at professional meetings, and via the center's electronic on-line services.

Results

Geological mapping of formations and fracture systems has added significantly to the knowledge of the geology of the Gilbertown area. Three-dimensional computer visualization of the Gilbertown fault system and associated structures has been constructed. This visualization is being used to develop structural models and is providing the straight-line cross sections required for area balance analysis. This information provides the basic information about fluid flow pathways necessary to determine the most effective recovery techniques in these areas.

Technologies/Methods

Advanced structural modeling using area balancing techniques; subsidence and thermal maturity modeling; remote sensing imagery

Publications/Reports

Pashin, J. C. and R. H. Groshong, 1997, Reservoir-Scale Deformation—Characterization and Prediction, presented at the American Association of Petroleum Geologists Hedberg Conference, Bryce, UT, June 22-28.

Groshong, R. H., 1997, Predicting Fractures from Area Balanced Cross Sections, presented at the American Association of Petroleum Geologists Hedberg Conference, Bryce, UT, June 22-28.

Pashin, J. C., 1997, Area Balance, Strain, and Fracturing in Coalbed and Chalk Reservoirs: Case Studies of Extensional Structures in the Black Warrior and Gulf Coast Basins, presented at the American Association of Petroleum Geologists Hedberg Conference, Bryce, UT, June 22-28.

Pashin, J. C., 1997, Area Balance in Extensional Structures: Comparison between the Black Warrior and Gulf Coast Basins, presented at the American Association of Petroleum Geologists Eastern Section Meeting, Lexington, KY, September 27-30.

Quarterly Progress Report, June 1996.

Quarterly Progress Report, September 1996.

Annual Report, March 1997.

Quarterly Progress Report, June 1997.

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Project Title

Using Microstructure Observation to Quantify Fracture Properties and Improve Reservoir Simulation

Partner

Bureau of Economic Geology, University of Texas at Austin

Project Location

New Mexico, Rio Arriba County, Blanco Mesaverde Gas Field, San Juan Basin
West Texas

Project Formations

Cliff House Formation
Point Lookout Formation
Spraberry Formation

Problem

Fracture properties are commonly a poorly known factor in formation evaluation and reservoir modeling simply because most large fractures do not intersect the wellbore where they can be detected and characterized. Current fracture detection methods–when they yield any information at all–often do not provide enough statistically significant data to establish fracture abundance and porosity patterns or to map shifts in fracture orientation within a given unit or from one unit to the next. Effective development of oil reservoirs requires more accurate description of the rock mass, as well as use of methods that can exploit better descriptions. Although fracture systems are complex in detail, it is basic information about the occurrence, orientation, and size of open fractures that is often lacking. Consequently, development decisions have greater risk and the effectiveness of fractured-reservoir simulators is impaired.

Objectives

Develop and verify new approaches for quantifying the occurrence of open natural fractures and fracture-controlled permeability anisotropy in sandstone oil reservoirs and develop new ways to incorporate such characterizations in dual-porosity fractured-reservoir simulators.

Project Description

The BEG is working with an industry user group to develop fracture data from core samples in BEG's Core Research Center. Research teams are conducting comprehensive analyses and imaging on outcrops that are analogous to reservoir strata to determine the relationship between microscale and macroscale fractures, and to document the depositional, structural, and stress/strain history of the units. Using Core Research Center samples, two reservoir formations are being analyzed in similar fashion, models developed that will show processes that open or close flow paths, and the results compared with the outcrop analog information. Fracture-mapping methods resulting from these two tasks is being used to develop improved simulation techniques for modeling the particular reservoirs under study and in adapting outcrop and core data for use in the models. Following verification of results, a comprehensive technology transfer effort will be conducted at professional meetings and through publications and workshops.

Results

The Mesaverde case study indicates that extrapolations of microfracture information to determine macrofracture characteristics are possible. However, further testing of the technique is necessary to understand the limitations of the techniques. Microfractures associated with compaction and tectonic forces need to be distinguished to establish adequate relationships between microfractures and macrofractures. The Spraberry case study indicates that microfractures accurately measured the main fracture trends.

Technologies

Mechanical modeling, Geostatistics, Fractal Analysis, Scanning Electron Microscopy, Cathodoluminescence Microscopy

Publications/Reports

Quarterly Report, June 1996

Quarterly Report, October 1996

Quarterly Report, December 1996

Annual Report, March 1997

Quarterly Report, June 1997

Quarterly Report, September 1997

Ortega, O., 1997, Natural Fractures in Mesaverde Outcrops and Core, presented at Fort Lewis College, Durango, CO, June 14.

Laubach, S., 1997, Fracture Properties from Rock Microstructure, presented at the American Association of Petroleum Geologists Hedberg Research Conference on Reservoir Deformation, Bryce, UT, June 23.

Laubach, S., 1997, Diagenetic Controls on Fracture Permeability, presented at the 36th U.S. Rock Mechanics Symposium, Columbia University, New York, NY, June 30.

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Project Title

Fractured Reservoir Discrete Fracture Network Technologies

Partner

Golder Associates, Inc.
Marathon Oil Company
Massachusetts Institute of Technology (MIT)

Project Location

Texas, Pecos and Crockett counties
Permian Basin, Yates Field Tracts 17 and 49

Project Formation

San Andres

Problem

Secondary and tertiary recovery technologies often are not applied to fractured reservoirs because specifically designed recovery processes that account for the unique characteristics of fracture network flow are not available. This industry-wide practice has left numerous large and small fractured reservoirs near abandonment producing at high water-oil ratios while retaining most of their original oil in place. Although field, laboratory, and computer simulation efforts are ongoing to improve the definition and design of fractured reservoir recovery processes, work is needed to supplement and accelerate the integration and development of these tools.

Objectives

Develop advanced technologies to improve oil production from fractured and compartmentalized reservoirs.

Project Description

Golder Associates and their partners are developing a reservoir fracture model that can be used to implement thermally assisted gravity segregation (TAGS), a cost-effective recovery process that combines the natural tendencies of fracture flow segregation, gravity segregation, and composition/thermal phase behavior in fractured reservoirs. Combining Marathon's data on fracture stress field and fluid-flow relationships and MIT's fracture-plane hydraulic data and fracture network modeling, Golder Associates are developing and applying a reservoir model to the West Texas Yates Field to demonstrate its ability to predict the TAGS process and assist in developing reservoir-specific oil recovery processes. This project addresses technology development in three areas: development of hierarchical fracture models, technologies for evaluating compartmentalization; and technologies for defining fracture sets. The development of hierarchical fracture models focuses on understanding the geology and fracture patterns of the Yates Field project study site. This requires a classification system for fractures according to their genetic process, a quantitative assessment of the geological history of the Yates Field, and initial quantification of fracture size, orientation, intensity, and location parameters based on Yates Field data. Project results will be presented to industry and academic experts

throughout the project term, both to obtain feedback and to disseminate useful technology to industry.

Results

Hierarchical fracture models have been developed. Fractured reservoir compartmentalization and tributary volume have been determined. Fractured reservoir data and production technologies have been integrated.

Technologies

Neural net technology for fracture set analysis; fracture network modeling

Publications/Information

Website: http://www.golder.com/niper/database/software.htm contains progress reports, peer reviewed papers, professional meeting presentations, site characterization data, algorithms and software, reservoir data and simulations, and technology transfer workshop information.

Quarterly Report, March 7, 1996 to June 6, 1996.

Quarterly Report, June 7, 1996 to August 31, 1996.

Research Report Reservoir Compartmentalization, November 15, 1996.

Quarterly Report, September 1, 1996 to November 30, 1996.

Annual Report, March 7, 1996 to February 28, 1997.

Quarterly Report, March 1, 1997 to May 31, 1997.

La Pointe, P. R., T. Eiben, W. Dershowitz, E. Wadleigh, 1997, Compartmentalization Analysis using Discrete Fracture Network Models, presented at the Fourth International Reservoir Characterization Technical Conference, Advances in Reservoir Characterization for Effective Reservoir Management, March 2-4, Wyndham Greenspoint Hotel, Houston, Texas.

LaPointe, P., 1997, Flow Compartmentatilization and Effective Permeability in 3-D Fracture Networks, presented at the International Soceity for Rock Mechanics Symposium, New York, New York, June 29–July 2.

Dershowitz, W, and T. Doe, 1997, Analysis of Heterogeneously Connected Rock Masses by Forward Modeling of Franctional Dimension Flow Behavior, presented at the International Society for Rock Mechanics Symposium, New York, New York, June 29–July 2.

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Project Title

Naturally Fractured Reservoirs: Optimized E&P Strategies Using a Reaction-Transport-Mechanical Simulator in an Integrated Approach

Partner

Science Application International Corp. (SAIC)
Indiana University Laboratory for Computational Geodynamics
Phillips Petroleum Company

Project Location

Texas, Midland County
Andector-Goldsmith Field, Permian Basin, West Texas

Project Formation

Ellenberger Formation, Clear Fork Formation

Problem

The ability to effectively exploit the tremendous resource of fractured reservoirs has been limited by the internal complexity of these reservoirs, the history of geologic influences during basin evolution, and the myriad interacting mechanical, hydrologic, and diagenetic processes that underlie their evolution and control reservoir fluid flow pathways. Production from these reservoirs has been hindered by the lack of predictive capabilities of fluid flow as well as by inadequate reservoir models for optimizing new technologies.

Objectives

Optimize modern exploration and production technologies for naturally fractured carbonate reservoirs using a new basin and reservoir simulator that automatically integrates recent advances in basin analysis with geochemistry, hydrology, and geomechanics.

Project Description

SAIC is working with Indiana University and Phillips Petroleum Company to integrate advanced geoscience techniques with reservoir engineering concepts to optimize exploration and production strategies for naturally fractured oil reservoirs. The location, reservoir characteristics, and spatial extent of reservoirs of interest are predicted by integrating seismic and other geological and engineering data with a geochemical-geomechanical simulator. Through this combination of physical and chemical laws with more traditional exploration and production data, SAIC is developing a reservoir model that can yield more efficient exploration and production strategies. The methodology and results are being demonstrated using the Andector-Goldsmith Field in the Permian Basin, West Texas. Key elements of SAIC's technology transfer plan include public outreach, and licensing and joint-venture arrangements. Workshops will be held to identify the needs of the resource owners in these areas. Publications will be prepared at the conclusion of major activities, and presentations will be made at national and local professional society meetings.

Results

A reaction-transport-mechanical (RTM) model developed at Indiana University Laboratory for Computational Geodynamics has been modified to model specific problems inherent in simulating the Permian Basin evolution. The structural geology and tectonics of the Permian Basin were determined using an integrated approach incorporating satellite imagery, aeromagnetics, gravity, seismic data regional subsurface mapping, and published literature.

Technologies

Reaction-transport-mechanical simulation model, remote sensing

Publications/Reports

Ortoleva, P., 1997, presented at the American Association of Petroleum Geologists Annual Meeting, Dallas, TX.

Hoak, T. and M. Shebl, 1997, presented at the American Association of Petroleum Geologists Southwest Regional Meeting, San Angelo, TX.

Ozkan, G. and P. Ortoleva, Mechanical Failure of Cavities in Poroelastic Media, submitted for publication.

Quarterly Report, July 10, 1996.

Quarterly Report, October 10, 1996.

Quarterly Report, January 10, 1997.

Annual Report, April 10, 1997.

Quarterly Report, July 10, 1997.

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Project Title

Characterization of Fractured Reservoirs Using Static and Dynamic Data: From Sonic and 3D-Seismic to Permeability Distribution

Partner

Southwest Research Institute (SwRI)

Project Location

Utah, Summit County
Lodgepole Field

Project Formation

Twin Creek Formation

Problem

In low porosity, low permeability zones, natural fractures are the primary source of permeability that affect both production and injection of fluids. The open fractures do not contribute much to porosity, but they provide an increased drainage network to any porosity. They may connect the borehole to remote zones of better reservoir characteristics. An important approach to characterizing fracture orientation and fracture is on the propagation of acoustic and seismic waves in the rock.

Objectives

Evaluate acoustic logging and 3D-seismic measurement techniques, as well as fluid flow and transport methods, to map permeability anisotropy and other petrophysical parameters to help understand reservoir fracture systems and associated fluid dynamics.

Project Description

SwRI is evaluating acoustic logging and 3D-seismic measurement techniques, as well as fluid flow and transport methods, to map reservoir fluid flow and other parameters to increase understanding of reservoir fracture systems and associated fluid dynamics. The principal application of this work is to identify and investigate the propagation characteristics of acoustic and seismic waves in the Twin Creek reservoir located in the overthrust area of Utah and Wyoming, owned by Union Pacific Resources. The focus of the project is to develop advanced concepts of borehole seismic, surface seismic, and fluid flow dynamic methods that relate permeability anisotropy to acoustic and seismic signatures. This can then be used to understand the reservoir fracture system and to predict the permeability distribution throughout heterogeneous reservoirs using multiphase production data. SWRI's technology transfer effort will identify companies interested in working in fractured reservoirs. Workshops will be organized to formulate emerging ideas, present research results, and obtain feedback.

Results

An analytical solution for plane-harmonic seismic waves propagating in a poroelastic anisotropic media was developed. Also, software was developed to calculate fluid pressure, the vector wavefield, and the displacement of the fluid relative to the solid. This software provided the relationship between permeability anisotropy and the dispersion and

attenuation seismic signatures. A 3-D streamline simulator for modeling multiphase flow and transport in heterogeneous permeable media was developed and tested. Results from the streamline model were validated against commercial numerical simulators. The simulator was more accurate and faster. A reservoir model was developed by integrating geological cross-sections with migrated seismic data, the velocity inversion, and FMS data recorded in horizontal wells. The data integration with synthetics derived from well log information delineated the major geological units of interest in the reservoir. The model was used to calculate synthetic seismic signatures for planning cross-well seismic surveys between wells at Lodgepole Field.

Technologies

Acoustic logging in fluid-filled boreholes, and analytical solutions for plane-harmonic seismic waves propagation in poroelastic anisotropic media, 3D-seismic measurement techniques, streamline simulator for modeling multiphase flow and transport

Publications/Reports

Parra, J. O., 1997, The Transversely Isotropic Poroelastic Wave Equation Including the Biot and the Squirt Mechanisms; Theory and Application, accepted for publication in *Geophysics*.

Parra, J. O., H. A. Collier, and B. Angstman, 1997, Seismic Signatures of the Lodgepole Fractured Reservoir in the Utah-Wyoming Overthrust Belt, presented at the Fourth International Reservoir Characterization Technical Conference, Houston, TX March 2–4.

Parra, J. O., H. A. Collier and T. E. Richards, 1997, Seismic Signatures of the Fractured Twin Creek Reservoir, Utah-Wyoming Overthrust Belt, presented at the Society of Exploration Geophysicists 67th Annual Meeting and Exposition, Dallas, TX, Nov. 2–7.

Peddibhotla, S., H. Cubillos, A. Datta-Gupta, and G. Xue, Multiphase Streamline Modeling in Three Dimensions: Further Generalizations and a Field Application, presented at the Society of Petroleum Engineers 1997 Symposium on Reservoir Simulation, Dallas, TX, June 1997.

Datta-Gupta, A. and S. Peddibhotla, Semi-Analytic Approach to Multiphase Flow Computations, published in the project newsletter.

Quarterly Report, March 7–May 31, 1996.

Quarterly Report, June 1, 1996, to August 31, 1996.

Quarterly Report, September 1, 1996, to November 30, 1996.

Annual Report , March 7, 1996.

Quarterly Report, March 1, 1997, to May 31, 1997.

Quarterly Report June 1, 1997, to August 31, 1997.

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Project Title

Advanced Fracture Modeling in the Uinta Basin (Utah) for Optimizing Primary and Secondary Recovery

Partner

TerraTek, Inc.

Project Location:

Utah, Uinta County, Duchesne County

Project Formation

Green River Formation

Problem

For decades, the Uinta Basin in northeastern Utah has been regarded by oil and gas operators as extremely hydrocarbon rich. However, thousands of feet of production casing have been set on uneconomic wells because of poorly understood reservoir performance coupled with high pour point, paraffinic oils.

Objectives

Integrate surface investigations with subsurface data from the Duchesne Fault Zone that affects oil reservoirs in the Uinta Basin, northeastern Utah. Apply basic and advanced geologic data, geomechanical engineering, and reservoir engineering to implement advanced techniques for fractured reservoir characterization along the Duchesne Fault Zone. Improve inefficient primary recovery in fractured reservoirs.

Project Description

TerraTek is implementing advanced geological, geotechnical, and reservoir engineering methods to model the complex fracture networks exhibited at the surface and in comparatively shallow settings along the Duchesne Fault Zone in the Uinta Basin. Activities include determining how fluids flow through matrix and fractured samples from Balcron and Duchesne fields, delineating the fracture systems and stress conditions and their effect on fluid flow as reservoir pressure changes, and predicting and verifying primary recovery in naturally fractured reservoirs using reservoir modeling and simulation. Technology transfer will include annual reporting in professional society meetings and journals. A short course will be organized in conjunction with a regional or national society convention.

Results

A computer code was developed to model the permeability of deformable fracture networks in two dimensions. This code has the ability to (1) model and include the stress tensor in either principal or non principal reference frame, and (2) account for the effects of both shear and normal stresses on fracture aperture. A computer algorithm was developed for modeling permeability in fractured rocks and tested using sample fracture patterns from several oil reservoirs.

Technologies

Surface Geochemistry and remote sensing; geostatistics and fractal analysis; dual-porosity fluid flow models

Publications/ Reports

Quarterly Report, July 1996.

Quarterly Report, September 1996.

Quarterly Report, December 1996.

Annual Report, April 1997.

Quarterly Report, June 1997.

Quarterly Report, September 1997.

Bruhn, R. L., D. Bering, S.R. Bereskin, C. Magnus and A. Fritsen, 1997, Field Observations and Permeability Modeling of Fracture Networks in Hydrocarbon Reservoirs, paper 041 in *J. Rock Mechanics and Mining Sci.* 34, NO. 3-4.

Brown, S. R. and L. Bruhn, Permeability of Deformable Fracture Networks, *J. Geophys. Res.*, in press.

Bereskin, S. R., R. L. Bruhn, A. Groeger, and B. A. Marin, 1997, Correlation of Fractured Surface Exposure to Aberrant Oil Production along the Duchesne Fault Zone, Northeastern Utah, *Natural Fracture Systems in the Southern Rockies*, J. C. Close and T. A. Casey (eds.), Four Corners Geological Society, Durango, CO.

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Project Title

Characterization and Simulation of an Exhumed Fractured Petroleum Reservoir

Partners

University of Utah
Pioneer Oil and Gas Company
University of Utah

Project Location

Nevada, White Pine County, Yankee gold mine in the southern Alligator Ridge mining district

Project Formation

Pilot Shale
Devil's Gate Limestone
Nevada Formation

Problem

Characterizing, predicting, and simulating the architecture of naturally fractured reservoirs is particularly challenging because vertical rotary drilling provides minimal insight into the geometry and character of the fractures and faults found in producing reservoirs. Fracturing also cannot be detected by surface seismic methods. Few reservoir analogs are available for studying lateral and vertical variations in geometry, density, and fluid flow properties of fractures and faults. As a consequence, development of methods for predicting the permeability of fractured and faulted systems has lagged behind techniques for estimating reservoir properties that result from sedimentary processes.

Objectives

Develop predictive models of fault and fracture distributions, geometries, and fluid flow characteristics. Develop a simulator capable of representing reservoir characteristics of a naturally fractured reservoir.

Project Description

University of Utah is using detailed field data from an analog fault- and fracture-controlled oil reservoir to develop predictive models of fault and fracture distributions, geometries, and fluid flow characteristics. The analog exhumed reservoir is exposed in open pit gold mines in the Yankee District, Nevada, and exhibits a suite of fault and fracture systems found in many hydrocarbon reservoirs. Subsurface data from a nearby wildcat well and a high-resolution reflection seismic line are used to construct the predictive models. The resultant models will be incorporated into numerical reservoir simulators to address production from fractured reservoirs and evaluate different production strategies. Technology transfer for the project will include publication of progress reports on the World Wide Web, presentation of papers at professional society meetings, publication in peer-reviewed journals, and a workshop and field trip covering the field and numerical simulation results of the project.

Results

Finite element models for fractured media were developed and are being tested. Fracture data from the West Crusher Pit gold mines in the Yankee District, Nevada, were collected and analyzed.

Technologies

Fractured Reservoir Simulator, Thematic Mapper (TM) image analysis

Publications/Reports/Presentations

Forster, C., 1997, Modeling Fault Zone Architecture and Permeability Structure, presented at the Geological Society of America Penrose Conference, Sept 10-15.

Forster, C., and S. Schulz, 1997, Evaluating Fault-Controlled Fluid Flow in an Exhumed Petroleum Reservoir, poster presented at the Geological Society of America Penrose Conference, Sept 10-15.

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PROJECT FACT SHEET

CONTRACT TITLE: Assist a Graduate Student, Peter Varney, in Energy-Related Research for Department of Energy

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CONTRACT PERFORMANCE PERIOD:
09/01/1997 to 12/31/1998

PROGRAM: Supporting Research
RESEARCH AREA:

OBJECTIVE: Provide research assistance to Peter Varney, a graduate research student at the Colorado School of Mines through the Associated Western Universities Incorporated.

METRICS/PERFORMANCE:
Products developed:

PROJECT DESCRIPTION:

Background:

Work to be performed: The project goal is to better define the relationship between stratigraphy and fractured reservoir geometry in the Lindrith Field area to enhance the oil and gas recover potential. It is anticipated that the results will be applicable throughout the Rock Mountain region where there is production from the Dakota Formation.

PROJECT STATUS:

Current Work:

Scheduled Milestones:

Accomplishments:

PROJECT FACT SHEET

CONTRACT TITLE: Geoscience Research - Advanced Heterogeneity Characterization

ID NUMBER: 95-A01 Task 05

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CONTRACT PERFORMANCE PERIOD:
11/01/1994 to 11/07/1996

PROGRAM: Supporting Research
RESEARCH AREA: Rsvr Characterization

OBJECTIVE: Provide better means for predicting production from fractured reservoirs and provide recommendations for improved production strategies. Results from laboratory measurements will be used to improve methods of modeling and simulating production from fractured reservoirs.

METRICS/PERFORMANCE:

Products developed: An analytical solution (mathematical model) was developed that predicts oil production during spontaneous brine imbibition into reservoir rock. Because the solution uses rock and fluid properties as model parameters, it should be particularly useful as a tool in developing improved oil recovery processes. Results from laboratory tests provide descriptions of the fluid recovery processes. Knowledge gained can be used in recovering additional oil resources from fractured reservoirs.

PROJECT DESCRIPTION:

Background: In the last decade, the petroleum industry has become increasingly aware that natural fracture networks have a significant impact on hydrocarbon recovery from many petroleum reservoirs. Production forecasting and strategies for increasing hydrocarbon production from naturally fractured reservoirs are currently topics of great interest to reservoir engineers and economists. Knowledge of capillary effects in and around fractures, fracture relative permeability characteristics, and the influence of changing stress fields on these effects is inadequate. Technology advances are needed in fractured reservoir analysis.

Work to be performed: Perform imbibition experiments on slabs of water-wet rocks to provide data to refine and/or validate an imbibition simulation model that was developed during FY 1994 at NIPER, and to see how the model applies to other fractured-rock scenarios. Perform similar laboratory experiments on selected fractured-samples in which fractures are oriented parallel and perpendicular to the free surfaces from which the imbibition process occurs. Refine the imbibition model to achieve suitable agreement with experimental results. Review the literature on current theories on flow through fractured rock. Perform selected laboratory experiments to determine the effects of stress on fluid-flow through fractured rock and multiphase fluid transmission qualities of open cracks. Develop techniques for measuring counter-current relative permeability functions.

PROJECT STATUS:

Current Work: The analytical imbibition model that was developed in FY 1994 was tested against results of other models described in the literature, experimental results, and results from numerical simulations. The analytical model provided spontaneous brine imbibition predictions that were in excellent agreement with saturation profiles, production history, and ultimate recovery data described in the literature. The analytical solution is particularly useful because rock and fluid properties are model parameters. Laboratory tests were performed to measure various parameters affecting production from fractured rock. Tests included measurements of spontaneous brine imbibition, fractured rock permeability reduction resulting from stress cycles, and fracture relative permeability measurements. Spontaneous imbibition tests on similar heterogeneous Berea sandstone plug and slab samples showed similar oil recovery histories even though the samples were of different sizes. Oil recoveries were proportional to the square root of time, in agreement with predictions by the analytical model. Open, oil-filled cracks blocked the imbibition process. Results from tests on cracked rock samples showed that fracture contributions to bulk permeability diminished with increasing confining pressure. Only a small fraction of original permeability was regained when the rock stress was reduced. Fracture relative permeability measurements with vertical oil and brine flow showed that relative permeabilities were not simply functions of fluid saturations, as is commonly assumed. Fluid densities and direction of fluid flow had pronounced effects on relative permeability functions. Progress was made toward designing test fixtures with hydrophilic and hydrophobic membranes for measuring capillary pressures during laboratory flow experiments.

Scheduled Milestones:

Progress Reports Qrtly

Accomplishments: An analytical solution (mathematical model) was developed that predicts oil production during spontaneous brine imbibition into reservoir rock. The model was validated using results described in the petroleum literature. The model accurately describes imbibition recovery processes for phenomena that can be simulated using a 1-dimensional representation. This study provides for the first time an analytical equation that uses rock and fluid properties as model parameters. The model should be particularly useful for evaluating ways to improve oil recovery through spontaneous imbibition processes.

Oil-filled, open cracks were found to act as barriers to spontaneous brine imbibition during laboratory tests on cracked rock slabs.

Tests in which a fractured sample was subjected to increasing and decreasing confining stress showed that, at least for this Berea rock, fracture contributions to bulk permeability diminished with increasing confining pressure. Only a small fraction of original permeability was regained when the rock stress was reduced.

Tests with vertical oil and brine flow through an open crack showed that relative permeabilities were affected by fluid densities and direction of fluid flow. For vertical flow, relative permeabilities were not simply functions of fluid saturations or fractional flows.

PROJECT FACT SHEET

CONTRACT TITLE: Geoscience Research - Heterogeneity Characterization

ID NUMBER: 97-A01 Task 05

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CONTRACT PERFORMANCE PERIOD:
11/01/1996 to 10/31/1997

PROGRAM: Supporting Research
RESEARCH AREA: Rsvr Characterization

OBJECTIVE: To characterize naturally fractured reservoirs and to describe relationships that control fluid mobility and oil recovery in fractured rock.

METRICS/PERFORMANCE:
Products developed:

PROJECT DESCRIPTION:

Background: In the last decade, the petroleum industry has become increasingly aware that natural fracture networks have a significant impact on hydrocarbon recovery from many petroleum reservoirs. Production forecasting and strategies for increasing hydrocarbon production from naturally fractured reservoirs are currently topics of great interest to reservoir engineers and economists. Knowledge of capillary effects in and around fractures, fracture relative permeability characteristics, and the influence of changing stress fields on these effects is inadequate. Technology advances are needed in fractured reservoir analysis.

Work to be performed: Perform research covering oil production from fractured rock, multiphase flow in fractures, and imbibition process simulation. Design and conduct spontaneous imbibition experiments on heterogeneous sandstone and limestone rock samples. Analyze results from laboratory experiments of multiphase flow in fractures. Generate representative heterogeneous media stochastically and deterministically. Upscale media properties such that vertical refinement or multiple interacting continua type dual porosity simulation models can be used for investigating imbibition in a single block or for a reservoir volume element consisting of multiple blocks. Upscaling methods including Wavelet analysis (developed at NIPER) and renormalization will be used.

PROJECT STATUS:

Current Work: Simulations of reservoir-condition imbibition in field-size (e.g. 20-ft tall), heterogeneous matrix blocks are in progress. Rock property distributions were generated using an analogous field variogram data and conditional simulation techniques. Upscaling methods were used to generate equivalent homogeneous properties for the heterogeneous block. Flow simulations at pressure above the bubble point were conducted using CMG's IMEX simulator.

Experimental investigation of imbibition and multiphase flow in fractures are in progress. Ambient-condition imbibition experiments using a field core of limestone lithology were completed. Thin fracture (67 um) flow experiments using low flow rates were completed.

Scheduled Milestones:

A topical report describing project activities and finding 09/97

Accomplishments: Simulation results indicate that gravity forces enhances recovery during imbibition in field-size matrix blocks. For the rock descriptions studied, a homogeneous matrix block with permeability and porosity obtained from geometric and arithmetic averaging, respectively, reproduced the results for the heterogeneous matrix block. Experimental results show that imbibition in the low-permeability, low-porosity limestone core is slower than that in the 100 md Berea core conducted before.

A paper entitled "2D X-ray Scanner and Its Uses in Laboratory Reservoir Characterization Measurements" was presented in the poster session at the Fourth International Reservoir Characterization Technical Conference, Houston, Mar. 2-4, 1997. Another paper entitled "Multiphase Flow in Fractures" will be presented at the 1997 International Symposium of the Society of Core Analysts, Calgary, Alberta, Canada, September 7-10, 1997. Technologies developed under this project were described to core analysts and engineers during presentations to others at oil companies and at our facilities.

PROJECT FACT SHEET

CONTRACT TITLE: Geoscience Research - Heterogeneity Characterization

ID NUMBER: 98-A01 Task 05

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CONTRACT PERFORMANCE PERIOD:
11/01/1997 to 10/31/1998

PROGRAM: Supporting Research
RESEARCH AREA: Rsvr Characterization

OBJECTIVE: Determine the relationship among capillary pressure in fractures and fracture characteristics and the distribution and role of capillary pressure in controlling fluid mobility and oil recovery mechanisms in fractured rock.

METRICS/PERFORMANCE:
Products developed:

PROJECT DESCRIPTION:

Background: In the last decade, the petroleum industry has become increasingly aware that natural fracture networks have a significant impact on hydrocarbon recovery from many petroleum reservoirs. Production forecasting and strategies for increasing hydrocarbon production from naturally fractured reservoirs are currently topics of great interest to reservoir engineers and economists. Knowledge of capillary effects in and around fractures, fracture relative permeability characteristics, and the influence of changing stress fields on these effects is inadequate. Technology advances are needed in fractured reservoir analysis.

Work to be performed: Perform imbibition experiments on slabs of water-wet rocks to provide data to refine and/or validate an imbibition simulation model that was developed during FY 1994 at NIPER, and to see how the model applies to other fractured-rock scenarios. Perform similar laboratory experiments on selected fractured-samples in which fractures are oriented parallel and perpendicular to the free surfaces from which the imbibition process occurs. Refine the imbibition model to achieve suitable agreement with experimental results. Review the literature on current theories on flow through fractured rock. Perform selected laboratory experiments to determine the effects of stress on fluid-flow through fractured rock and multiphase fluid transmission qualities of open cracks. Develop techniques for measuring counter-current relative permeability functions.

PROJECT STATUS:

Current Work:

Scheduled Milestones:

Accomplishments:

PROJECT FACT SHEET

CONTRACT TITLE: Geoscience Research - Imaging Technology

ID NUMBER: 98-A01 Task 03

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CONTRACT PERFORMANCE PERIOD:
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PROGRAM: Supporting Research
RESEARCH AREA: Rsvr Characterization

OBJECTIVE: This project supports reservoir description and advanced oil recovery processes research and development, especially in the areas of reservoir chemistry, physics,
and rock-fluid interactions at the micro-and macroscopic scales (pore to whole core scales). This project is aimed at advancing the understanding of fundamental processes involved in oil recovery by developing, applying and refining cross-cutting imaging techniques and technologies.

METRICS/PERFORMANCE:
Products developed:

PROJECT DESCRIPTION:

Background: This project supports reservoir description and advanced oil recovery processes research and development, especially in the areas of reservoir chemistry, physics, and rock-fluid interactions at the micro-and macroscopic scale (pore to whole core scales). This project is aimed at advancing the understanding of fundamental processes involved in oil recovery by developing, applying and refining cross-cutting imaging techniques and technologies.

Work to be performed: The CT scanner, automated minipermeameter, and computer assisted petrographic image analysis will be used to characterize the rock heterogeneity at core scale for ripple laminated sample characteristic of class 1 reservoirs. Correlations and scaling procedures for the heterogeneities will be derived for laboratory corefloods using these procedures. Results of the imaging research will be related to field data in class 1 reservoirs and to other IOR research projects. The nuclear magnetic resonance (MR) measurements will be expanded to the low field (0.05 T) regime at frequencies close to those used by the MR logging tools. The emphasis is to improve the design of pulse sequences and the interpretation in calculating the reservoir engineering parameters such as porosity, permeability and saturation. The current high resolution magnetic resonance imaging (MRI) microscopy will be expanded to include multi-nuclear imaging and will be applied to imaging chemical gels, polymers, miscible gas, and microbial systems and fractured systems.

PROJECT STATUS:

Current Work:

Scheduled Milestones:

Accomplishments:

PROJECT FACT SHEET

CONTRACT TITLE: Improved Oil Recovery (Heavy Oil) - Core and Log Analysis from NPR #1

ID NUMBER: AC/15054 Task 08

B & R CODE: AC1005000

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CONTRACT PERFORMANCE PERIOD:
09/01/1994 to 11/30/1994

PROGRAM: Supporting Research
RESEARCH AREA: Rsvr Characterization

OBJECTIVE: Evaluation of the 29R reservoir in order to determine technically feasible and economic methods of recovery that minimize bypassed and trapped oil.

METRICS/PERFORMANCE:
Products developed:

PROJECT DESCRIPTION:

Background: Based on the currently available analyses of the NPR #1 well 372-32R core, the 29R reservoir does not look attractive. Experiments and analyses outlined in the three reports from this project indicate that additional tests and activities may be needed to confirm this conclusion. Additional tests may also prove helpful in determining a technically and economic method to produce the 29R reservoir.

Work to be performed: The work performed under this task focused on evaluation of core material and correlation of log and core data from a well in the 29R reservoir at the Naval Petroleum reserve Number 1(NPR #1). The overall objective of this and previous phases of this work is to evaluate the 29R reservoir in order to determine technically feasible and economic methods of recovery that minimize bypassed and trapped oil.

The proposed work consisted of (1) complete the core analysis from well 372-32R to provide porosity and gas permeability data, (2) determine a correlation between core-based petrophysical data and log data, and (3) provide a summary based on the data available from this and previous phases of the work on well 372-32R of the optimal production strategy.

Previous work done at the NIPER labs on the 29R core from well 372-32R has shown that the 29R reservoir consists of very well indurated fractured siliceous silty shale and thin "crumbly" sandstones deposited in very deep waters, possibly by turbidity currents. Development of this reservoir will need to account for the stratigraphic distribution of the porous sands within the tight siliceous shales as well as the fracture network, in addition to properties of the rock and fracture system.

PROJECT STATUS:

Current Work: The project has been completed. A report entitled "Petrographic Analysis, Special Core Analysis, and Computerized Tomographic Analysis of Core from Well 372-32R Naval Reserve Number 1 Elk Hills, CA" has been delivered to the Bartlesville Project Office. This report is the deliverable for Task 8.

Scheduled Milestones:

Publish final report 12/94

Accomplishments: Geological analysis of core material from NPR #1 well 372-32R indicated that the interval is characterized by fining up depositional cycles that are typically less than 1 foot thick. Cycles consist of a lower sandstone interval, a middle laminated silty sand and interbedded shale interval, and an upper dark-colored shale interval recognized in the interval 6,277.6 - 6,289.6 feet, where the core was cleaned. Only the lower sandstone interval from each depositional cycle has a well developed pore system.

Petrophysical properties vary at a frequency much greater than can be recorded on typical production logs such as the gamma ray, neutron porosity, or the density porosity logs. There is no overall (larger scale) vertical trend of permeability for the interval 6,277.6 - 6,289.6 feet for which detailed minipermeameter data was recorded. Because of the high frequency of change among petrological and petrophysical properties and because the logs record running averages of properties over a 2-3 foot interval, no correlation could be found between core-based petrophysical and log data.

A summary of previous work accomplished on this project was also included in the current report.

PROJECT FACT SHEET

CONTRACT TITLE: Advanced Reservoir Characterization in the Antelope Shale to Establish the Viability of CO2-Enhanced Oil Recovery in California's Monterey Formation Siliceous Shales -- Class III

ID NUMBER: DE-FC22-95BC14938

B & R CODE: AC1010000

CONTRACT PERFORMANCE PERIOD:
02/12/1996 to 06/11/2001

DOE PROJECT MANAGER:
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PROJECT SITE
CITY: Bakersfield **STATE:** CA
CITY: Kern County **STATE:** CA
CITY: Beuna Vista Hills Field **STATE:** CA

OBJECTIVE: Increase oil recovery from the Monterey/Antelope Siliceous Shale through the application of an innovative reservoir management plan.

METRICS/PERFORMANCE:
Products developed: The project is still in the data collection and analysis stage. Besides gaining a deeper understanding of this complex reservoir, it is hoped that new/improved technologies and methodologies for increasing oil production in siliceous shale will be developed.
Noteworthy Technological Successes: None to date.
Incremental Production from Project: None to date.
Application of Results: None to date.

TECHNOLOGIES USED: Core/fluid analysis, borehole imaging, NMR logging, geochemical fingerprinting, well tests, reservoir modeling; CT scanning, numerical simulation, cross-well seismic, acoustic anisotropy, pilot CO2 injection.

PROJECT DESCRIPTION:

Background: The reservoir discovered in 1952 has produced only 9 million bbl of oil representing 6.5% of the estimated 130 million bbl of original-oil-in-place. The current status of the reservoir indicates that it is producing at 40% of its original reservoir energy. In addition, production from wells in this field, and in the Antelope Shale in general, has been declining, and the wells are in danger of being abandoned. Several methods were tried to improve the reservoir productivity. Technologies such as waterflooding, acid treatments, and induced fractures were implemented and, although some were proven successful, the overall oil recovery from the Antelope Shale still remains low at 6.5%.

Unique/Novel Aspects: The application of state-of-the-art reservoir characterization and reservoir management techniques to establish the viability of CO2 enhanced oil recovery.

Expected Benefits/Applications: Chevron expects that conducting this project will improve the reservoir description and find new ways to recover the large amounts of potential reserves that could not be produced by current methods. Chevron hopes that this new innovative method will recover 5% to 15% of the estimated reserves potential of remaining oil.

Work to be performed: This project will demonstrate the economic viability and widespread applicability of an innovative reservoir management plan for a CO2 flood project in the fractured siliceous shales of the Monterey Formation. Advanced reservoir characterization and fracture analysis will be applied to optimize the design of the CO2 - based enhanced oil recovery project. The first step will be an application of a variety of advanced reservoir characterization techniques to determine the production characteristics. The production characteristics will be used in laboratory coreflood and reservoir models to evaluate how the reservoir will respond to the application of advanced secondary recovery and EOR processes. The second step will be to design and implement an advanced EOR pilot demonstration by injecting CO2 in an immiscible phase.

PROJECT STATUS:

Current Work: The reservoir characterization of the Brown and Antelope siliceous shale is continuing. New core, well log, seismic and engineering data is being collected, analyzed and incorporated into a comprehensive reservoir model.

Problems and Resolutions: Initial processing of shear-wave USP data revealed unexpected and so far unexplained source-generated noise at some levels, but prospects seem good to subtract out the S-wave data and allow high-quality analysis.

Accomplishments: Core well was drilled and logged in July, 1996. Improved wellsite core handling procedures were developed. Routine core analysis, and many of the special core analyses have been completed. Data from 160 wells has been compiled in a database and used for high resolution structural mapping. Vertical seismic profile data has been collected, processed and analyzed. Crosswell seismic data has been collected and processed. These are the first crosswell reflection images to be obtained in any oil field in the San Joaquin Valley. Outcrop analysis of rock fractures has been completed and shows how fractures can act as permeable pathways. Part 1 of the regional tectonic synthesis has been completed. A two day team partners meeting was held in December, 1996 with display of core. A core workshop and 7 oral presentations were given at the May, 1997 American Assoc. Petroleum Geologists Pacific Section meeting, Bakersfield, CA. Also two papers were published in the Rock Fracture Project Workshop, Stanford University and one paper is in press in the AAPG Bulletin.

Recent Publications: 1) S.K. Dholakia, "Outcrop to Reservoir: Importance of Faulting to Hydrocarbon Migration in the Monterey Formation, California", Stanford Rock Fractured Project, Vol. 7, M1-14, Stanford University, Stanford, CA 1996. 2) S.K. Dholakia, Aydin, A., Pollard, D.D., and Zoback, M.D., "Hydrocarbon Transport and Shearing Processes in the Antelope Shale, Monterey Formation, San Joaquin Valley, California", presented at in the 1996 Annual American Association of Petroleum Geologists Convention, San Diego, California, May 19-22, 1996. 3) S.K. Dholakia, Lore, J., Brankman, M., and Roznovsky, T., "Fault Control on Hydrocarbon Migration in the Monterey Formation, California", Field Trip Guidebook, Stanford Rock Fracture Project, Stanford University, Stanford, CA, 1996.

Ongoing/Future Work: Continue with the reservoir characterization study to include drilling new core well and conducting core analysis, and initiating fracture characterization studies.

Recent/Upcoming Technology Transfer Events: Morea, M., T. Zalan, and J.L. Jacobs, May 14, 1997. Buena Vista Hills Reservoir Characterization Study, Chevron/DOE Class III Reservoir Project. Presentation and core workshop: AAPG Pacific Section, in Short Course, "Advances in Reservoir Description Techniques, as Applied to California Oil and Gas Fields", Bakersfield, CA.

Bilodeau, B and S. Smith, May 16, 1997. "Reservoir Characteristics and Improving Recovery in Monterey-type Siliceous Shales" Symposium; AAPG Pacific Section, Bakersfield, CA. Seven papers on the class project were presented.

PROJECT FACT SHEET

CONTRACT TITLE: Simulation Studies to Evaluate the Effect of Fracture Closure in the Performance of Naturally Fractured Reservoirs.

ID NUMBER: DE-AC22-90BC14654

B & R CODE: AC1510100

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CITY: Tulsa **STATE:** OK
CITY: **STATE:**
CITY: **STATE:**

CONTRACTOR: K&A Energy Consultants Inc.

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CONTRACT PERFORMANCE PERIOD:
09/18/1990 to 12/31/1993

PROGRAM: Supporting Research
RESEARCH AREA: Geoscience

OBJECTIVE: 1) Evaluate the specific reservoir conditions leading to significant reduction in oil or gas recovery as a result of fracture closure, and 2) evaluate the degree of improved oil recovery from such reservoirs that can be achieved by innovative fluid injection techniques capable of maintaining pressure support within the reservoir. The study will be conducted using K&A's state-of-the-art dual porosity simulator.

METRICS/PERFORMANCE:
Products developed:

PROJECT DESCRIPTION:

Background: A significant amount of the total oil and gas reserves in the United States is contained in reservoirs where natural fractures play a dominant role in the performance. Increased attention is being given to naturally fractured reservoirs because of the significant reserve potential and because of the advancements in horizontal drilling which may aid in the recovery from such reservoirs. Examples of naturally fractured reservoirs in the United States include Elk Basin (Montana, Wyoming), Spraberry (Texas), and Yates (Texas).

Work to be performed: Numerical simulation studies will provide the major tool for evaluating the effects of fracture closure on the performance of naturally fractured reservoirs. Studies will be conducted using TRIAD, K & A's state-of-the-art three-dimensional, three-phase, dual porosity simulator. The model is capable of predicting the reduced flow capacity that occurs as natural fractures close with pressure depletion (increased overburden stress). The algorithm describing the pressure sensitive fracture behavior will be incorporated to match measured data. For this study, it will be necessary to build in the code which will incorporate horizontal wells.

The performance of naturally fractured reservoirs will be evaluated using the simulator, for both horizontal and vertical wells using two models - 1) no pressure sensitivity and 2) pressure sensitive fractures.

PROJECT STATUS:

Current Work: Final Report is being published.

Scheduled Milestones:

#1-Set up TRIAD model for predicting naturally-fractured reservoir performance using horizontal & vertical wells.	09/91
#2-Conduct simulation studies w/TRIAD for Task 1 conditions where fractures are assumed to close with stress.	09/92
#3-Identify reservoir conditions where fracture closure causes severe production problems and evaluate innovative approaches for improving oil recovery and prepare Final Report.	09/93
#4-Final report published	4/94

Accomplishments: The Austin Chalk in the Pearsall Field in South Texas was selected as the prototype fractured reservoir for this work. During the first year, simulations of vertical and horizontal well performance were made assuming that fracture permeability was insensitive to pressure change. Sensitivity runs indicated that the simulator was predicting the effects of critical reservoir parameters in a logical and consistent manner. The results confirmed that horizontal wells could increase both rate of oil recovery and total oil recovery from naturally fractured reservoirs.

In the second year, the performance of the same vertical and horizontal wells was re-evaluated with fracture permeability treated as a function of reservoir pressure. To investigate sensitivity to in situ stress, differing loading conditions were assumed. The highest condition assumed all principal stress components equaled the overburden stress. The lower stress cases assumed the horizontal stress components were unequal and less than the overburden stress.

Simulated natural depletions confirm that pressure sensitive fractures degrade well performance. The severity of degradation worsens when the initial reservoir pressure approaches the average stress condition of the reservoir, such as occurs in over pressured reservoirs. Simulations with water injection indicate that degradation of permeability can be counteracted when reservoir pressure is maintained and oil recovery can be increased when reservoir properties are favorable.

PROJECT FACT SHEET

CONTRACT TITLE: Telluric Surveys - Research & Development to Provide Resolutions to Producibility Problems

ID NUMBER: G4P51722

B & R CODE: 95-A14

CONTRACT PERFORMANCE PERIOD:
10/15/1995 to 12/31/1995

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PROJECT SITE

CITY: Creek County	**STATE:** OK
CITY: Coal County	**STATE:** OK
CITY:	**STATE:**

OBJECTIVE: Test the capability of tellurics as an additional tool to define subsurface features. Reducing risk and enhancing the potential of exploratory and or development drilling in today's economic environment.

METRICS/PERFORMANCE:
Products developed:
Noteworthy Technological Successes:
Incremental Production from Project:
Application of Results:

TECHNOLOGIES USED:

PROJECT DESCRIPTION:

Background: Test the capability of tellurics as an additional tool to define subsurface features, reducing risk and enhancing the potential of exploratory and/or development wells. A subsurface structural anomaly has been located in Section 2-Township 14 North - Range 8 East, Creek County, Oklahoma by a telluric geophysical survey. Drill an Ordovician, Wilcox sandstone well to test the accuracy of Electrotelluric signals to locate and define a subsurface structure.

Unique/Novel Aspects:

Expected Benefits/Applications:

Work to be performed: Pan Western plans to mill a window in the production casing string and drill a short radius horizontal well 500 ft. to 800 ft. in a northwest-southeast direction to tap into the vertical fracturing system caused by extensive faulting in the area. The project is located in Centrahoma field in Coal County, Oklahoma. The proposed well will be drilled in the Wapanucka limestone reservoir which is at a depth of 5560 ft - 5758 ft. The horizontal wellbore should contact gas reserves that would otherwise remain in the reservoir without a horizontal wellbore or additional vertical wells.

PROJECT STATUS:

Current Work:

Problems and Resolutions:

Accomplishments: A well was drilled, and the Wilcox sandstone was dry and not on structure. The telluric survey as used here is unable to predict formation taps, although this method has reportedly been used successfully in other fields.

Recent Publications:

Ongoing/Future Work:

Recent/Upcoming Technology Transfer Events:

PROJECT FACT SHEET

CONTRACT TITLE: Reservoir Characterization of the Monterey "Shale"

ID NUMBER: FEW 0001

B & R CODE: AC1005000

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CITY: **STATE:**
CITY: **STATE:**

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CONTRACT PERFORMANCE PERIOD:
02/15/1993 to 09/30/1995

PROGRAM: Supporting Research
RESEARCH AREA: Rsvr Characterization

OBJECTIVE: The objectives of this research are to compile accurate geological, reservoir, and producing characteristics of California's Monterey "Shale" heavy oil resource, to determine which characteristics are favorable for enhanced oil recovery, and to recommend specific EOR processes for testing in one or more known accumulations.

METRICS/PERFORMANCE:
Products developed:

PROJECT DESCRIPTION:

Background: Although the Monterey Formation in California contain some sands locally, it is predominantly very fine-grained sedimentary rock principally composed of diatom skeletons, with variable amounts of terrigeneous material, which has been altered by compaction and increasing temperature to produce siliceous rocks ranging from siliceous mudrocks and diatomite to porcellanite and cherts. It is these fine-grained siliceous rocks that are commonly called the Monterey "Shale."

The Monterey "Shale" presents a large target for enhanced oil recovery. Some estimates are as high as 16 billion barrels of heavy oil and bitumen in place.

Work to be performed: The BPO heavy oil database identifies the Monterey "Shale" in California, as a major resource of heavy oil, and contains some information on lithology, reservoir size, producing history, and oil properties needed to begin assessing its potential as an enhanced oil recovery (EOR) target. In three concurrent phases, this research is intended to build, on the BPO Database foundation, an augmented database to stimulate one or more commercial field tests of EOR technology, cost-shared by DOE.

Phase 1. Review critically the geological, reservoir, production data contained in the BPO Heavy Oil database.

Phase 2. Obtain and analyze data for EOR field projects that have been conducted in the Monterey "Shale" reservoirs and, as available, in other fractured rocks (e.g., carbonates) containing heavy oil and having low matrix permeability which might serve as analogs.

Phase 3. A limited amount of modeling with STARS or a similar on-isothermal code will be used to investigate the physical mechanisms of oil displacement from Monterey "Shale" matrix blocks to fractures and hence to the producing wells for processes believed to be applicable for EOR.

PROJECT STATUS:

Current Work: The project has been completed. The data is being transferred to BDM-OK for integrating into the TORIS database.

Scheduled Milestones:

PHASE 1-Review and Change the BPO Heavy Oil Database Geologic-Reservoir and Production Data for Monterey "Shale"	09/95
Publish Revised Database for the Monetrey "Shale" Reservoirs	09/95
PHASE 2-Review Field EOR Projects Conducted in Monterey "Shale" Reservoirs	09/95
Publish Report on Field EOR Projects	09/95
PHASE 3-Publish Report on Recommended EOR Processes	09/95

Accomplishments: All milestones were completed, except the writing of the reports. The data was transferred to BDM-OK for integrating into the TORIS database.

PROJECT FACT SHEET

CONTRACT TITLE: Mapping Conductivity Fractures Using a Through Tubing Deployed Geophone Array (Mono-cable telemetry for a through-tubing geophone array)

ID NUMBER: FEW 9197

B & R CODE: AC1005000

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PROJECT SITE
CITY: Los Alamos **STATE:** NM
CITY: **STATE:**
CITY: **STATE:**

CONTRACTOR: Los Alamos Nat'l Lab

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CONTRACT PERFORMANCE PERIOD:
06/01/1992 to 09/30/1995

PROGRAM: Supporting Research
RESEARCH AREA: Rsvr Characterization

OBJECTIVE: To evaluate the potential for using microseismicity induced through production, injection, and stimulation to determine the location of conductive fractures that control oil and natural gas recovery. Develop monitoring tools to minimize the cost and deferred production required to obtain the seismic data.

METRICS/PERFORMANCE:

Products developed: 1) A through-tubing single geophone deployment was demonstrated in Prudhoe Bay Field. 2) The first through-tubing deployable, two sonde, geophone array has been designed and fabricated to operate on a commercial 1-11/16" OD (production logging) platform. A single sonde prototype has been successfully field tested. 3) Multiple geophone arrays have been used successfully in shallow wells to demonstrate the effectiveness of multiple sondes with significant spacial separation in improving the potential for seismic mapping.

PROJECT DESCRIPTION:

Background: Los Alamos National Laboratory has been at the forefront of microseismic monitoring technology development since it was first used to map fractures during stimulation of precambrian granite to create manmade Hot Dry Rock reservoirs. For the past 7 years the Laboratory has been working with the oil industry to adapt and evaluate Hot Dry Rock seismic mapping technology to map fractures, joints, and faults in petroleum reservoirs. Los Alamos demonstration projects have been limited to wells which could be readily prepared for monitoring by removing tubing and setting a bridge plug over open perforations. The results of the early deployments were encouraging enough to generate interest in fielding demonstrations in wells where pulling tubing would be too costly or risky. A request to place tools in the Lisburne Field on the Alaskan North Slope initiated a proposal to develop a small diameter, through-tubing deployable geophone tool. Through-tubing operations were demonstrated in ARCO's Prudhoe Bay Field completed with large tubing using Los Alamos 3-1/4" OD slimline tools. The results of this deployment have had a major impact on the direction of the project and the geophone array tool design that has been developed.

Work to be performed: Los Alamos has been evaluating the potential for using microseismicity induced through production, injection, and stimulation to determine the location of conductive fractures that control oil and natural gas recovery. A major element of this project is to develop monitoring tools to minimize the cost and deferred production required to obtain the seismic data. Los Alamos has developed a 1-11/16" diameter slimhole geophone receiver that includes a two-sonde array. The Los Alamos prototype includes two complete sondes including: 3-axis orthogonal geophones, analog telemetry, independent single arm anchors with backup supports, inclinometers, collar locators, telemetry, and wire pass-through in the anchor housing. Schlumberger, a CRADA participant in slimhole tool development, has provided field and design support and a standard commercial 1-11/16" OD operating platform for the sondes including cable heads, connectors, and housings. In FY 1995 the scope of the project was increased so to include development of preliminary concept for running the geophone array on mono-cable.

PROJECT STATUS:

Current Work: Data analysis and review of the through-tubing deployed geophones in Prudhoe Bay Field deployment using Los Alamos 3-1/4" OD tools is complete. The first 1-11/16" OD sonde has been fabricated, assembled, bench tested, and field tested. Fabrication of a second and third sonde has been completed and assembly and bench testing is 100% complete. Field testing of the 2-level array configuration is 25% complete. Los Alamos has completed a conceptual design of a mono-cable telemetry system for the slimhole geophone array.

Scheduled Milestones:

Conceptual design of slimhole geophone array tools	12/93
Design and fabrication of first sonde complete	11/94
Bench test and preliminary field test of array tool	05/95
Conduct calibration test in Amoco test well(s)	12/95
Conduct fracture mapping demonstration with 1-11/16" array tool in the Opelika	03/96
Conduct Vertical Seismic Profile performance test at Schlumberger test site	07/96

Accomplishments: Two Los Alamos 3 1/4" OD slimline geophones were modified for through-tubing operations in pressurized, inclined wells. They were fielded in a monitoring and simulation well in Prudhoe Bay Field. Perforation shots in the simulation well and microseismicity were successfully monitored from inside tubing and in a cemented liner in the monitoring well. A review of the Prudhoe Bay Field seismic mapping demonstration by Los Alamos, ARCO and Schlumberger personnel in September, 1993 lead to the design and specification of a two-sonde array tool run on a seven-conductor wireline. The new tool will enable seismic mapping with through-tubing deployment capability.

A prototype 1-11/16" OD sonde has been fabricated, assembled, and bench and field tested. Two additional slimhole geophone array sondes have been fabricated and assembly and bench testing is 100% complete. Field testing of the 2-level array configuration is 25% complete.

Los Alamos has field tested the first single-level prototype sonde in 3 oil/gas field well environments and is working with Schlumberger to plan field demonstrations and testing of the two sonde array in test wells and commerical wells. The field test with Schlumberger may include a performance evaluation in a vertical seismic profile application if they can provide the test site, field personnel and hardware. Texaco will furnish its geophone test wells and air guns for a calibration test of the array. Monitoring of a stimulation treatment with the two sonde array in Enserch Explorations, Inc.'s Opelika gas field is planned for early March, 1996. The goal of the field tests is to demonstrate economical mapping of conductive flow paths in oil and natural gas reservoir using microearthquake data.

PROJECT FACT SHEET

CONTRACT TITLE: Advanced Seismic Geodiagnostics-Borehole Acoustic Source/ Instrumentation for Fracture Mapping

ID NUMBER: FEW A053

B & R CODE: AC1015000

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CITY: **STATE:**
CITY: **STATE:**

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CONTRACT PERFORMANCE PERIOD:
03/01/1988 to 09/30/1998

PROGRAM: Environmental-Oil
RESEARCH AREA: Rsvr Characterization

OBJECTIVE: To advance the state-of-the-art in borehole seismic imaging of reservoir fractures through the development of new downhole measurement capabilities and new analytical methods for processing and interpretation of microseismic events.

METRICS/PERFORMANCE:
Products developed: Under a Cooperative Research and Development Agreement (CRADA No.LA93C10075) with Schlumberger Wireline Services a through-tubing, 1-11/16 inch OD, 2-level geophone package was designed and prototyped. The geophone package is now available for cooperative research applications.

PROJECT DESCRIPTION:

Background: The current limitations of developing useful reservoir models are, 1) major engineering decisions on field development are made early in nmodel development stages when the least detailed information is known, and 2) the high-resolution but localized well data is sparsely distributed and cannot readily be integrated with low-resolution but continuous-coverage surface-seismic data. The capability to gather data early in field development at low cost and in hostile environments requires new borehole tools and greater access to reservoir rock.

Work to be performed: Under a separate program, Los Alamos is investigating the feasibility of drilling micro-boreholes (~1 inch), a capability that opens up the possibility of directly measuring subsurface reservoir properties and delineating reservoir boundaries at much lower cost and more systematically than is possible using current technologies limited to commercial exploration and development wells. Realization of the benefits of micro-drilling will require miniaturization of conventional logging tools as well as developing new instruments for fluid detection and monitoring reservoir processes. Los Alamos has been at the forefront of microseismic monitoring technology, a powerful technique for mapping conductive reservoir fractures at 100's of meters from a borehole. In addition, we have been developing new borehole receivers for deployment in production tubing (2-3/8-in and greater) and very small diameter boreholes or borehole annuli, in an effort to demonstrate lower-cost applications of borehole seismic imaging techniques.

In this project we extend these efforts to improve capabilities of conventional logging technology and develop new borehole measurement techniques. Three major tasked are proposed: 1) Upgrade and complete the through tubing geophone array. 2) Determine the requirements and availability of components for u[grades of downhole electronics for use in high temperature Gulf wells. 3) Conduct field experiments to investigate the sources of non-shear-slip seismic events observed during injection operations.

PROJECT STATUS:

Current Work: The performance of the through-tubing, slim hole geophone array (SLGA) is being evaluated in tests in conjunction with an industry-sponsored hydraulic fracture in Cotton Valley, Texas and with Texaco at their Humble borehole seismic test facility. The former test will compare the performance of the SLGA with that of annular, cemented-in geophones, while the latter will assess the SLGA's performance in casing and tubing in comparison with microhole hydrophones, geophones, and accelerometers.

Los Alamos has monitored many hydraulic fracture reservoir stimulations for the presence of microseismicity. In several of these tests, hundreds of anomalous seismic signals, called long-period events, were observed with characteristics quite distinctive from the typical shear-slip events used for fracture mapping. The temporal occurrence of these events appears to correlate with injection activity suggesting that they are related to fluid movement or transient pressure responses far from the injection point. Similar observations have been reported by other investigators. These anomalous signals may provide more information on reservoir permeability paths. We most recently observed this phenomenon again in a Permian Basin field during an ongoing CO2 and waterflood operation. We plan to investigate the nature of these events and their relevance to production.

Scheduled Milestones:

Complete microearthquake cluster analysis for joint structure	09/96
Complete the CRADA with Schlumberger Wireline Services	03/97
Publish results of work from previous years including cluster analysis	01/97
Complete engineering tests and upgrades to the SLGA	09/97

Accomplishments: Data were collected at the industry--sponsored hydraulic fracture in Cotton Valley and are currently being analyzed. Modifications and improvements to the SLGA were completed, including a new mounting for the locking arm-motor drive, the cable head, control software, and control panel functions. The CRADA with Schlumberger Wireline Services was completed. Results of past years' field work in Clinton County, Kentucky, and the Giddings Field, Texas, and of progress in analysis were published. A patent disclosure for the chemical components and electrical initiator of an explosive borehole seismic source was filed with the United States Patent Office.

PROJECT FACT SHEET

CONTRACT TITLE: Characterization of a Fractured Dolomite Reservoir in Preparation for Water Flooding. (PARTNERSHIP)

ID NUMBER: FEW PG12

B & R CODE: AC1510100

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CITY: **STATE:**

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CONTRACT PERFORMANCE PERIOD:
04/01/1989 to 12/30/1992

PROGRAM: Lt Oil
RESEARCH AREA: Partnership/Oil Recovery Technology

OBJECTIVE: To evaluate the application of seismic mapping technologies developed by LANL for acquisition of information important for optimizing the design of waterfloods in fractured oil reservoirs.

METRICS/PERFORMANCE:
Products developed:

PROJECT DESCRIPTION:

Background: The Chaveroo San Andres Field is similar to other fields producing oil from the San Andres Dolomite in southeast New Mexico and Texas. After primary production, water flooding is employed to improve the long-term production from the field. Because existing well locations bear no specific relationship to natural and stimulated fractures in the San Andres rock, injected water can prematurely communicate between wells through fractures and thus bypass porosity of the rock. This situation could be worked to advantage if the location of primary conductive fractures could be determined in advance. Injection wells could be located parallel to these fractures to sweep additional oil toward the fractures and then to production wells. Los Alamos was in collaboration with Murphy Operating Corporation in a series of field experiments to evaluate the application of seismic mapping technologies to obtain data for optimizing the design of water floods in fractured oil reservoirs.

Work to be performed: The objective of this research is to determine the extent to which the microseismicity of aging oil fields that is associated with withdrawal and injection of reservoir fluids can be used to locate fractures controlling production and hence to provide engineering data with which to design enhanced recovery from these fields.

PROJECT STATUS:

Current Work: Project completed with a final report being reviewed and completed.

Scheduled Milestones:

Well selection and field investigation	07/90
Field emplacement of three downhole geophones	11/90
Microseismic data collection in Tomahawk Field, starting	11/90
and will continue on to this period of time.	09/91
Microseismic data processing starting.	03/91
Final Report due.	03/93

Accomplishments: Microseismicity was monitored in the Chaveroo field using a single 3-component downhole geophone in June-July, 1989 while a pilot waterflood operation was started. Intermittent monitoring during the waterflood suggested episodic occurrence of microearthquakes. Microseismic events were at times detected at rates up to several hundred per day and at distances exceeding one mile, but mostly within 3000 ft, of the monitor well. Hodogram locations of events show seismicity occurring mostly within the San Andres dolomite near the depth interval of production. The follow-up experiment was conducted in the Tomahawk oil field located 10 miles west of the Chaveroo site. Production in the Tomahawk is also from the San Andres dolomite and like the Chaveroo field, is also in a late stage of primary production. However, no waterflood operation took place in the Tomahawk field during monitoring. In July, 1990 a geophone package was sequentially deployed in 4 wells to measure ambient noise levels and monitor seismicity occurrence. A long term monitoring network of geophone packages was then deployed in 3 wells with full-time monitoring coverage capability. No seismicity within or near the geophone array was detected during normal production activity over a 3.5-month period of constant monitoring. However, during this time events occurring along the southern flank of the field, 2.5 miles from the array were detected at a rate of 1 to 2 per week. These events are most closely associated with a salt water disposal well injecting about 400 bbl per day into the permeable zones of the San Andres. In a third phase of the experiment, production was increased nearby the geophone array by putting 7 previously offline wells on flush production. This was followed by normal cycled, pumped production and pressure build-up measurements on 3 of the 7 wells. No seismicity was detected during the third phase of monitoring which lasted seven weeks. From the limited experience of these monitoring experiments, it appears that microseismicity occurs in these aged reservoirs only while fluid injection is taking place.

PROJECT FACT SHEET

CONTRACT TITLE: Fracture Mapping and Slimhole Geophone Array (PARTNERSHIP)

ID NUMBER: P-10

B & R CODE: AC1005000

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DOE PROJECT MANAGER:
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PROJECT SITE
CITY: Los Alamos **STATE:** NM
CITY: Carthage Gas Field **STATE:** TX
CITY: Opelika Field **STATE:** TX

CONTRACTOR: Los Alamos Nat'l Lab
Union Pacific Resources
ADDR: P.O. Box 1663
EES-DO/MS D443
Los Alamos, NM 87545

PRINCIPAL INVESTIGATOR:
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CONTRACT PERFORMANCE PERIOD:
06/23/1991 to 09/01/1997

PROGRAM: Supporting Research
RESEARCH AREA: Partnership/Oil Recovery Technology

OBJECTIVE: To demonstrate the feasibility of using induced microearthquakes to map stimulation and natural fractures and fluid flow in oil reservoirs. To reduce the cost of mapping using single wireline arrays and through-tubing deployments.

METRICS/PERFORMANCE:

Products developed: 1) Demonstrates of mapping natural, productive, reservoir fractures using production-induced microseismicity with low-cost, long-term ($20,000, 6-months) monitoring in shallow oil fields of south-central Kentucky. The Kentucky application revealed a detailed fracture system, unresolved by any other technology, which radically altered the operators' conceptual reservoir models used in exploration and field development. 2) Observations of high-level background reservoir microseismicity associated with normal production activity in giant oil fields (Prudhoe Bay and Ekofisk). 3) Geophones were successfully deployed in wells with open perforations or exposed open hole sections. Noise levels were temporarily controlled by maintaining a column of water over the perforations (water kill). This successful demonstration greatly expands the potential application of geophone mapping and is crucial to the success of through-tubing deployed geophones. 4) Multiple geophone arrays have been used successfully in shallow wells to demonstrate the effectiveness of using multiple sondes with significant spacial separation to improve seismic mapping.

PROJECT DESCRIPTION:

Background: Wellbore deployed seismic receivers have been used routinely to collect microseismic data in crystalline rock at the Los Alamos Hot Dry Rock geothermal site. The spatial distribution of seismicity has been shown to be related to the presence of fluids and fluid flow paths in the reservoir. Similar experiments need to be performed in oil reservoirs. If sufficient numbers of microseismic events can be observed, their location patterns should indicate reservoir flow paths that will be important in planning production flooding schemes, the placement of new wells, and the azimuthal orientation of new horizontal wells.

Work to be performed: The focus is on demonstrating the application of detecting and mapping induced reservoir microearthquakes to map reservoir fractures that control the occurrence and flow of hydrocarbons in oil and gas reservoirs. To accomplish this, downhole, 3-component geophone tools will be deployed within or close to production depths in monitor wells during hydraulic fracture operations in two field environments: The Opelika gas field and the Cotton Valley Gas Field, east Texas.

PROJECT STATUS:

Current Work: Field testing of the two-sonde configuration of the slimline (1-11/16") tool is complete. Deployment during the Cotton Valley Fracture Imaging test was completed. A common-mode noise problem in the 2-sonde configuration needs to be eliminated. The mount for the anchor-arm motor was modified to assure more reliable performance. Preparations are being made for deployment of the 2-sonde, slimline tool and an additional single-level tool in the Opelika gas field during a hydraulic fracture operation. Data analysis from the first hydraulic fracture monitoring test from the Opelika field has been completed. The fifth long-term monitoring test in Clinton County, Kentucky has been completed. Documentation of the Kentucky experiments has been completed.

Scheduled Milestones:

2-Station Experiment, Opelika Field, Texas	10/94
Additional Multiple-Station Experiment, Clinton County, KY	06/95
Multiple-Station Experiment, Weld Co., CO	08/95
Single Station demonstration of production-induced seismicity, Permian Basin,	04/96
Two-level slimhole geophone demonstration in Opelika Gas field	10/97
Two-level slimhole geophone demonstration in Cotton Valley Gas field	05/97
Final Documentation for Slimhole Geophone Array	02/97

Accomplishments: Five long-term (3 to 6 months) monitoring tests in Clinton Co., KY have demonstrated the feasibility of mapping natural reservoir fractures using production-induced microearthquakes. Low-angle thrust fault structures within the reservoir have been mapped using the microseismicity. Drill tests, well-logs and production records indicate that the seismically active fractures have been drained by previous production. The results imply that similar, undrained, low-angle fractures are the targets for exploration and development drilling. A regional, conceptual geologic model of the Clinton County reservoirs, using well-log and microseismic data, has been developed for the study area. The Kentucky Geological Survey completed a final report summarizing the geology of the area.

A four tool deployment in HS Resources wells in Wattenberg Field failed to detect seismicity during a small, high rate fracture stimulation. The operator indicated that the fracturing treatment pressure response was unusually low. Two of the four tools were set in rat hole below open perforations and a low noise environment was maintained for 6 to 12 hours by killing the wells with water.

A prototype slimhole (1-11/16" OD) sonde has been completed and field tested in 3 oil/gas field environments. The acoustic performance of the tool compares favorably with the Los Alamos 3-1/4" OD tools used for most of the oil field seismic mapping experiments to date. Field testing demonstrating reliable performance of the two-level array configuration is complete. The tool was successfully deployed during the Cotton Valley Fracture Imaging test.

PROJECT FACT SHEET

CONTRACT TITLE: The Study of Fracture Characterization and Fluid Flow.

ID NUMBER: DE-FG22-91BC14837

B & R CODE: AC0530000

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PROJECT SITE
CITY: Washington **STATE:** DC
CITY: **STATE:**
CITY: **STATE:**

CONTRACTOR: National Academy of Sciences
Office of Contracts & Grants
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CONTRACT PERFORMANCE PERIOD:
09/18/1991 to 10/01/1993

PROGRAM: Supporting Research
RESEARCH AREA: Exploratory Research

OBJECTIVE: Review, synthesize and integrate current research and provide guidance for field application for characterization of fracture networks and fluid flow in rock fractures.

METRICS/PERFORMANCE:
Products developed:

PROJECT DESCRIPTION:

Background: The committee, consisting of twelve experts who volunteer their time, will meet eight times during the 24 month project to coordinate their findings and the writing of the various chapters for the study. A final report will be the deliverable resulting from this effort, and is tentatively titled "Annual Review of U.S. Progress in Rock Mechanics-Fracture Characterization and Fluid Flow".

Work to be performed: The purpose of the study is to review, synthesize and integrate current research and provide guidance for field applications for characterization of fracture networks and fluid flow in rock fractures. The review will include fracture origin, morphology, geophysical imaging, flow and transport analysis and modeling. The study will have application in a number of areas including fractured oil and gas reservoirs.

Other objectives to the study include: A) identify and review the status of current research in fracture characterization and fluid flow through fractured media; B) identify federal and other governmental activities and problem areas in the field; C) explore mechanisms to advance the field; D) offer guidance on recent progress in the field to governmental agencies sponsoring research in this area.

PROJECT STATUS:

Current Work: Project is complete. Awaiting final report.

Scheduled Milestones:

Committee mtg/federal presentations; develop report outline	05/91
Initial report writing at second committee meeting	07/91
First review of manuscript at third committee meeting	10/91
Review report at fourth committee meeting	01/92
Committee-approved expansion of scope	03/92
Revise report at field committee meeting	05/92
Review, augment draft (final) sixth committee meeting	01/93
Committee approved draft	10/93
Report submitted for NRC review	11/93
NRC report review comments received	02/94
Report published	12/94

Accomplishments: At this time a first draft has been prepared.

PROJECT FACT SHEET

CONTRACT TITLE: Improved Efficiency of Miscible CO2 Floods and Enhanced Prospects for CO2 Flooding Heterogeneous Reservoirs.

ID NUMBER: DE-FG22-94BC14977

B & R CODE: AC1005000

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DOE PROJECT MANAGER:
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PROJECT SITE
CITY: Socorro **STATE:** NM
CITY: **STATE:**
CITY: **STATE:**

CONTRACTOR: NM Inst. of Mining & Tech

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CONTRACT PERFORMANCE PERIOD:
04/18/1994 to 05/31/1997

PROGRAM: Supporting Research
RESEARCH AREA: Extraction Research

OBJECTIVE: A research effort aimed at improving the effectiveness of CO2 flooding in heterogeneous reservoirs. The investigation of new concepts that can be applied by field operators within the next two to five years. The activities consists of research in three closely related areas: 1) further exploration of the applicability of selective mobility reduction (SMR) in the use of foam flooding, 2) the possibility of higher economic viability
of floods at slightly reduced CO2 injection pressures, and 3) taking advantage of gravitational forces during low interfacial tension (IFT), CO2 flooding in tight, vertically fractured reservoirs.

METRICS/PERFORMANCE:

Products developed: Task 1: A number of rock types and surfactants have been identified that exhibit positive SMR (selective mobility reduction). A model has been developed to simulate reservoir performance that assesses the economic usefulness of the SMR property. A device has been modified to measure foamability and durability of foam. A screening procedure has been developed to identify potential foaming agents with good SMR properties.

Task 2: Coding has been completed for a horizontal model and two foam options that been added to MASTER (DOE's pseudo miscible reservoir simulator) and one foam option has been added to UTCOMP (UT Austin's compositional reservoir simulator). Validation tests for all options are showing their usefulness.

Task 3: Reservoir condition apparatus to measure IFT and gravity drainage have been designed, built, and are in use. Models have been derived to predict IFT and gravity drainage results.

PROJECT DESCRIPTION:

Background: New concepts are being considered that have the potential of recovering oil currently thought unrecoverable by the industry. The concepts being investigated could provide a more favorable response from the use of foam for achieving mobility control in CO2 floods, the possibility of obtaining good oil recovery efficiency by using less CO2 than is commonly practiced in field operations, and taking advantage of gravity drainage and imbibition in CO2 flooding vertically fractured reservoirs.

Work to be performed: The overall goal of this new project is to improve the efficiency of miscible CO2 floods and enhance the prospects for flooding heterogeneous reservoirs. This objective will be accomplished by extending ongoing experimental research in three areas: 1) foams for selective mobility control in heterogeneous reservoirs, 2) reduction of the amount of CO2 required in CO2 floods, and 3) miscible CO2 flooding in fractured reservoirs.

PROJECT STATUS:

Current Work: The three-year project has been completed and the final report submitted.

Scheduled Milestones:

TASK 1 - CO2-Foams for Selective Mobility Reduction in Heterogeneous Reservoirs	05/97
TASK 2 - Reduction of the Amount of CO2 Required in CO2 Floods	05/97
TASK 3 - Low IFT Mechanisms with Applications to Miscible CO2 Flooding in Fractured Reservoirs	05/97
TASK 4 - Technology Transfer	05/97

Accomplishments: Task 1 - We progressed well in our studies of selective mobility reduction (SMR). This property promises to improve displacement efficiency in CO2 floods by reducing the effects of reservoir heterogeneity. The uneven distribution of fluid in heterogeneous composite cores was verified and we verified the positive effect of foam in compensating for the effects of heterogeneity in the cores. A potential method for quick screening of surfactants to assess their potential as SMR agents was developed using interfacial tension (IFT) at reservoir pressure.

Task 2: A phase behavior data bank was developed that concentrates on the effects of pressure, temperature, and fluid compositions on the development of efficient CO2 displacements under reservoir conditions. Coreflood tests were used to identify and quantify a number of variables in foam flooding; effects of flow rate, gas foam quality (gas volume fraction), and surfactant concentration. Foam and horizontal well features were developed for reservoir simulation. The foam model has been tested and verified using field data. The horizontal feature was tested using a Society of Petroleum Engineers test Problem.

Task 3: Multi phase flow behavior was investigated in fractured reservoirs. We improved the apparatus for measuring IFT at reservoir conditions. A new method for calculation of low IFT was developed and shown to work at low IFT. The new method is based on a static force balance on the lower half of the pendant drop. Another area of major achievement was the development of a new mathematical model based on Darcy's law and film flow theory to describe free-fall gravity drainage with equilibrium fluids. The ability to measure and predict IFT and describe gravity drainage are necessary developments toward the goal of improving oil recovery in fractured systems.

Task 4: A CO2-Oil Recovery Forum for exchange of CO2-Oil Recovery information was held in Socorro, NM, October 23 24, 1996. Present were representatives from 10 major oil companies, 16 independent oil companies, and 12 other organizations. Numerous presentations and publications have been produced and others have been accepted for future publication related to this project.

PROJECT FACT SHEET

CONTRACT TITLE: Improved Efficiency of Miscible CO2 Floods and Enhanced Prospects for CO2 Flooding Heterogeneous Reservoirs.

ID NUMBER: DE-FG22-97BC15047

B & R CODE: AC1005000

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CITY: Socorro **STATE:** NM
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CONTRACTOR: NM Inst of Mining & Tech

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CONTRACT PERFORMANCE PERIOD:
05/09/1997 to

PROGRAM: Supporting Research
RESEARCH AREA: Extraction Research

OBJECTIVE: The objective of this work will consist of an experimental research effort aimed at improving the effectiveness of CO2 flooding in heterogeneous reservoirs. The intent is to investigate new concepts that can be applied by field operators within the next two to five years. The proposed activities will consist of experimental research in three closely related areas: 1) further exploration of the applicability of selective mobility reduction (SMR) in the use of foam flooding; 2) the possibility of higher economic viability of floods at slightly reduced CO2 injection pressures, and 3) taking advantage of gravitational forces during low IFT, CO2 flooding in tight, vertically fractured reservoirs.

METRICS/PERFORMANCE:
Products developed:

PROJECT DESCRIPTION:

Background: New concepts are being considered that have the potential of recovering oil currently thought unrecoverable by the industry. The concepts being investigated could provide a more favorable response from the use of foam for achieving mobility control in CO2 floods, the possibility of obtaining good oil recovery efficiency by using less CO2 than is commonly practiced in field operations, and taking advantage of gravity drainage and imbibition in CO2 flooding vertically fractured reservoirs.

Work to be performed: The overall goal of this project is to improve the efficiency of miscible CO2 floods and enhance the prospects for flooding heterogeneous reservoirs. This objective will be accomplished by extending ongoing experimental research in three areas: 1) foams for selective mobility control in heterogeneous reservoirs, 2) reduction of the amount of CO2 required in CO2 floods, and 3) miscible CO2 flooding in fractured reservoirs.

PROJECT STATUS:

Current Work:

Scheduled Milestones:

Accomplishments:

PROJECT FACT SHEET

CONTRACT TITLE: Aid to Independents

ID NUMBER: G4P60384

B & R CODE: 95-A14

CONTRACT PERFORMANCE PERIOD:
06/30/1996 to 05/31/1997

DOE PROJECT MANAGER:
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CONTRACTOR: Pan Western Energy Corp.

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Tulsa, OK 74119

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FAX:
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PROJECT SITE

CITY: Tulsa	**STATE:** OK
CITY:	**STATE:**
CITY:	**STATE:**

OBJECTIVE: Extend the wellbore of the Mayer #3 well horizontally 500 to 800 feet to tap into the vertical fracturing system caused by the extensive faulting in the area.

METRICS/PERFORMANCE:
Products developed:
Noteworthy Technological Successes:
Incremental Production from Project:
Application of Results:

TECHNOLOGIES USED:

PROJECT DESCRIPTION:

Background: On February 1, 1995, Pan Western Energy Corporation acquired fourteen (14) producing gas wells in Coal County, OK. The leasehold estate is located on the western edge of the Arkoma Basin in southeast Oklahoma and consists of approximately 4,500 acres currently being held by production.

While gas production from the wells is from a number of different formations, primary production is from the Wapanucka Limestone. The Wapanucka Limestone is a high pressure, low permeability limestone that, because of its low permeability, drains a very small radius around the wellbore (approximately 60 acres). However, the formation is vertically fractured due to severe faulting in the area and is capable of producing grater quantities of gas if the vertical fracturing system can be tapped into and exploited.

Unique/Novel Aspects:

Expected Benefits/Applications:

Work to be performed: For over three years, Pan Western has been investigating the possibility of horizontally extending the wellbores of producing wells it owns in the area to tap into this vertical fracturing system. Until very recently, the only available method to do this was by utilizing either long or medium radius extension techniques during the initial drilling of a well because this method required the use of a downhole motor that was unable to fit inside conventional 4 1/2" and 5 1/2" casing. In the last five years, a short radius extension system has been developed that permits the turn from vertical to horizontal to be made inside conventional 4 1/2" and 5 1/2" casing within fifty vertical feet. The system is also a surface driven system.

PROJECT STATUS:

Current Work:

Problems and Resolutions:

Accomplishments:

Recent Publications:

Ongoing/Future Work:

Recent/Upcoming Technology Transfer Events:

PROJECT FACT SHEET

CONTRACT TITLE: Advanced Reservoir Characterization and Evaluation of CO2-Gravity Drainage in the Naturally Fractured Spraberry Reservoir -- Class III

ID NUMBER: DE-FC22-95BC14942

B & R CODE: AC1010000

CONTRACT PERFORMANCE PERIOD:
07/24/1995 to 07/23/2000

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PRINCIPAL INVESTIGATOR:
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PROJECT SITE
CITY: Spraberry Field **STATE:** TX
CITY: Midland County **STATE:** TX
CITY: **STATE:**

OBJECTIVE: Determine the technical and economic feasibility of continuous CO2 injection in the naturally fractured reservoirs of the Spraberry Trend.

METRICS/PERFORMANCE:
Products developed: None to date.
Noteworthy Technological Successes: None to date.
Incremental Production from Project: None to date.
Application of Results: None to date.

TECHNOLOGIES USED: Core/fluid analysis, outcrop analysis, fracture analysis, borehole imaging logging, well tests, reservoir modeling, numerical simulation, horizontal drilling, infill drilling, CO2 injection.

PROJECT DESCRIPTION:

Background: At least 15% of all oil remaining in Class 3 (slope-basin and basin clastic) reservoirs may be in the Spraberry Trend. Project participants estimate that currently no less than 6 billion bbl remain in Spraberry reservoirs. The presence of fractures is the dominant influence on performance. Waterflooding was initiated in the Spraberry in the 1950s, but recovery of oil from this process has been relatively poor and only marginally economic. Ultimate recovery under current operations for the Spraberry is extremely low, no greater than 12% of the original oil in place.

Unique/Novel Aspects: Prior to this project, no project has evaluated CO2 injection for enhanced oil recovery in the Spraberry. Because the Spraberry is a fractured reservoir, "conventional wisdom" would imply that recoveries will not be substantially improved. The current project will test the hypothesis that when CO2 is injected under near-miscible conditions, significant amounts of oil previously unaffected by water injection will be drained by a gravity mechanism from the rock pores into the fractures and moved to producing wells.

Expected Benefits/Applications: Success of the proposed technique could improve production in the proposed pilot study area by as much as 85 barrels of oil per day, resulting in an incremental recovery of as much as 31 thousand bbl of oil. Extrapolated to the Spraberry Trend as a whole, incremental recoveries could reach over 125 million bbl of oil, and access to additional potentially recoverable oil could be preserved. The techniques being used in this project are specifically related to CO2 flooding of fractured reservoirs. The results of the project should therefore translate to similarly fractured reservoirs of other geological classes. Applying such techniques on a widespread scale could result in incremental oil recoveries in the 2-3 billion bbl range.

Work to be performed: In this project advanced reservoir characterization methodologies will be developed and applied to describe, understand, and model the Spraberry fracture system. Laboratory studies will investigate the potential interaction of the low-permeability rock matrix with the fracture system in the presence of CO2 to produce oil via a gravity-assisted drainage mechanism. Reservoir modeling studies will assess the technical and economic potential of the proposed approach, and a pilot demonstration will be designed and implemented based on the modeling results. New wells will be drilled, including a horizontal well which will be cored to evaluate reservoir rock and fracture characteristics.

PROJECT STATUS:

Current Work: Currently finalizing geographic maps to volumetrically determine OOIP and to provide final input parameters for the reservoir simulation. Finalizing imbibition and gravity drainage laboratory work.

Problems and Resolutions: None to date.

Accomplishments: The center well in the proposed pilot area has been drilled (E.T. O'Daniel #37). Data retrieved from this well include cores, logs, pressure analysis and pre and post frac production results. Most recently over 400' of horizontal core was taken from the E.T. O'Daniel #28. This core is the first known horizontal core taken from the Spraberry and has provided a world class set of fracture data for the Upper Spraberry. On January 30-31, 1997 in Midland, Parker & Parsley & DOE sponsored a one day symposium (repeated on the second day) to celebrate the long history of the Spraberry and provide participants with an opportunity to view the horizontal core. The symposium was provided to a total audience of 170 people representing both independent and major producers.

Recent Publications: Two papers were presented at the Permian Basin Oil and Gas Recovery Conference in Midland, Texas, March 27-29, 1996. They are: (a) SPE 35469, "Reservoir Characterization and CO2 Pilot Design in the Naturally Fractured Spraberry Trend Area," D.S. Schechter, New Mexico Petroleum Recovery Research Center and (b) SPE 35224, "Characterization of the Naturally Fractured Spraberry Trend Shaly Sands Based on Log and Core Data," A.K. Banik and D.S. Schechter, New Mexico Petroleum Recovery Research Center. Also, D.S. Schechter and B. Guo of the New Mexico Petroleum Recovery Research Center presented SPE 35170 "Mathematical Modeling of Gravity Drainage After Gas Injection into Fractured Reservoirs" at the SPE/DOE Tenth Symposium on Improved Oil Recovery in Tulsa on April 21-24, 1996.

Ongoing/Future Work: Drill and core a dual lateral horizontal well.

Recent/Upcoming Technology Transfer Events: Presentation at Class 2 workshop, Midland, Texas, May 15, 1996. AAPG, May 19-22, 1996, T.D. Sheffield, P. McDonald, D.S. Schechter, R. Baker, and L. Teufel presented a paper, "CO2 Pilot Design in the Naturally Fractured Spraberry Trend: Project Update and Spraberry Rock Model." SPE Annual Convention, October 6-9, 1996 in Denver, D.S. Schechter, P. McDonald, T. Sheffield, R. Baker, poster session (SPE 36657), "Integration of Laboratory and Field Data for Development of a CO2 Pilot in the Naturally Fractured Spraberry Trend." Spraberry Symposium Workshop, Jan. 30, 1997, Midland, TX.

PROJECT FACT SHEET

CONTRACT TITLE: Theoretical and Experimental Study of Multiphase Flow in Fractured Reservoirs

ID NUMBER: G4S60336	**CONTRACTOR:** Prairie View A&M
B & R CODE: 95-A01	**ADDR:** P.O. Box 397
CONTRACT PERFORMANCE PERIOD: 05/15/1996 to 05/31/1997	Prairie View, TX 77446
	PRINCIPAL INVESTIGATOR:
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DOE PROJECT MANAGER:	**FAX:**
NAME: Robert E. Lemmon	**INTERNET ADDRESS:**
LOCATION: BDM	
PHONE: (918) 337-4387	**PROJECT SITE**
	CITY: **STATE:**
	CITY: **STATE:**
	CITY: **STATE:**

OBJECTIVE: Conduct research and training in the application of theoretical and experimental techniques to the problem of multiphase flow and transport trough fractured reservoirs.

METRICS/PERFORMANCE:
Products developed:
Noteworthy Technological Successes:
Incremental Production from Project:
Application of Results:

TECHNOLOGIES USED:

PROJECT DESCRIPTION:

Background: Fractured oil and gas reservoirs represent a significant energy resource for our nation. Recovery of oil from these reservoirs is relatively inefficient compared to the unfractured reservoirs. Better understanding of transport of fluids from matrix blocks to fracture is needed for the improvement of oil recovery from this huge resource.

Unique/Novel Aspects:

Expected Benefits/Applications:

Work to be performed: In this study experiments will be conducted and theoretical models will be proposed to understand the role of diffusion, dispersion, capillarity, buoyancy and pressure gradients in transfer of multiphase fluids from regions of low permeability, matrix blocks, to high permeability, fractures. High pressure experiments will be conducted in sandstone samples. Effects of phase behavior on matrix to fracture mass transfer mechanisms will be evaluated. Models to calculate transfer functions between the main regions will be developed. An upscaling procedure will be derived to use the microscale results on macro and reservoir scales. Compositions will be identified that give optimal recovery in this kind of reservoir.

PROJECT STATUS:

Current Work:

Problems and Resolutions:

Accomplishments:

Recent Publications:

Ongoing/Future Work:

Recent/Upcoming Technology Transfer Events:

PROJECT FACT SHEET

CONTRACT TITLE: Research Project on Fractured Petroleum Reservoirs

ID NUMBER: DE-AC22-91BC14835

B & R CODE: AC1510/AC1505

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DOE PROJECT MANAGER:
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PROJECT SITE
CITY: Palo Alto **STATE:** CA
CITY: **STATE:**
CITY: **STATE:**

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CONTRACT PERFORMANCE PERIOD:
09/25/1991 to 11/30/1993

PROGRAM: Supporting Research
RESEARCH AREA: Geoscience

OBJECTIVE: Quantification of the physics of multiphase flow in fractured porous media is the major goal. Since the role of capillary, diffusive, gravity, and viscous forces will be addressed, the topics of natural depletion, gas injection (both miscible and immiscible), and water injection in light and heavy oil reservoirs will all be studied in a unified approach.

METRICS/PERFORMANCE:
Products developed:

PROJECT DESCRIPTION:

Background: The mechanisms of fluid transfer between matrix blocks and fractures and the interaction of matrix blocks for immiscible and miscible flow are not well understood. Consequently, complicated numerical models currently in use cannot yield reliable results. A key element to recovery enhancement of fracture petroleum reservoirs and the use of models to simulate those reservoirs is an adequate knowledge of multiphase flow in fractured porous media.

RERI is a non-profit research organization carrying out highly focused research. For a number of years, RERI has led a consortium of industrial companies to study the "experimental study of immiscible and miscible flow in fractured media." Currently, member companies are - Amoco Production Company, BP Exploration Inc., Elf-Aquitaine, Japan National Oil Company, Maersk Oil & Gas, Mobil R&D, Petrofina Exploration, Phillips Petroleum, Saudi Aramco, Texaco, Unocal, and DOE.

Work to be performed: Some 20% world wide oil reserves are from fractured petroleum reservoirs. The Monterey formation in California, and Austin Chalk in Texas are intensely fractured and highly complex reservoirs which contain vast quantities of oil. Initial production rate under natural depletion could be high followed by a sharp rate drop. In both Monterey and Austin Chalk, matrix contribution to the production is unknown. EOR by water, gas (miscible or immiscible) or CO2 injection could produce significant quantities of oil. The literature contains very little basic information and most of the published material deals with a single block under drainage or imbibition. Comprehensive research work both experimental and theoretical to better understand capillary, gravity, viscous, and diffusive forces would reveal the physical principles and also formulate physical principles. Practicing reservoir engineers could use results for fractured field studies.

PROJECT STATUS:

Current Work: The consortium work continues. A new grant was initiated to continue support for the work.

Scheduled Milestones:

TASK II. Miscible Fluid System 12-24 Months started 01/92.	
A. Data collection and analysis using C5/C10 fluids	12/92
B. Theoretical model development - One D Case	12/92
TASK III. Viscous Flooding 16-36 Months	
A. Data collection and analysis	08/93
B. Theory and simulation model	12/93
TASK IV. Theoretical Work 24-36 Months	
A. Theory of miscible displacement in fractured porous media	09/93
B. Theory of Critical Gas Saturation	12/93
C. Unified model for fractured and heterogeneous porous media	12/93
TASK V. Water Injection 24-36 Months	
A. Design and construction of apparatus	09/93

Accomplishments: Three important issues related to gas oil displacement in fractured petroleum reservoirs have resolved as a result of our work.

1. Oil flows mainly in the matrix in the two phase region. This point has been demonstrated experimentally and theoretically.

2. The flow of oil from one matrix to another is through liquid bridges in the fractures. Significant recovery enhancement could be achieved by a 50 percent reduction in gas oil surface tension.

3. Miscible displacement in fractured porous media is much more efficient than the general belief based on current literature models. The crossflow between the matrix and fracture is a very pronounced process. Our experimental and theoretical work support this conclusion.

Some sixteen papers (mostly SPE publications) have been written from the work carried out in the fractured reservoirs research consortium.

PROJECT FACT SHEET

CONTRACT TITLE: Research Program on Fractured Petroleum Reservoirs

ID NUMBER: DE-AC22-93BC14875

B & R CODE: AC1005000

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CONTRACT PERFORMANCE PERIOD:
09/30/1993 to 09/29/1996

PROGRAM: Supporting Research
RESEARCH AREA: Extraction Research

OBJECTIVE: The main objectives of this project are to develop a full understanding of the role of diffusive, capillary, gravity and viscous forces in the flow of fluids in fractured porous media. The plan is to conduct a comprehensive experimental and theoretical research program to better understand the basic mechanisms of oil recovery and recovery enhancement of fractured petroleum reservoirs.

METRICS/PERFORMANCE:

Products developed: The results from water injection in one set of experiments on Austin Chalk with permeabilities less than 0.01 md reveal considerable recovery -- about 25 percent. The oil production from the Austin Chalk in the depletion stage may be mainly from the fracture storage. However, by injecting water, considerable oil recovery from the tight matrix can be achieved. The same well could be for both injection and production.

PROJECT DESCRIPTION:

Background: The mechanisms of fluid transfer between matrix blocks and fractures and the interaction of matrix blocks for immiscible and miscible flow are not well understood. Consequently, complicated numerical models currently in use cannot yield reliable results. A key element to recovery enhancement of fracture petroleum reservoirs and the use of models to simulate those reservoirs is an adequate knowledge of multiphase flow in fractured porous media.

Work to be performed: This project is divided into four tasks. Task 1 - Miscible Displacement in Fractured Porous Media studies miscible displacement in fractured porous media both experimentally and theoretically. Task 2 - Critical Gas Saturation, is divided into two subtasks; a) theoretical study of critical gas saturation, and b) visual measurements of gas evolution and flow in porous media. Task 3 - Immiscible Gas-Oil Gravity Drainage in Fractured/Layered porous media includes the theoretical and experimental study of immiscible gas-oil flow in both fractured and layered media by a unified approach. Task 4 - Water Injection in Fractured/Layered Porous Media, includes experimental and theoretical work; the experimental work includes water injection in fractured Austin Chalk cores and Berea sandstone matrix blocks.

PROJECT STATUS:

Current Work: The project is progressing on schedule

Scheduled Milestones:

Accomplishments: Several important issues related to gas oil displacement in fractured petroleum reservoirs have resolved as a result of our work.

1. Oil flows mainly in the matrix in the two phase region. This point has been demonstrated experimentally and theoretically.

2. The flow of oil from one matrix to another is through liquid bridges in the fractures. Significant recovery enhancement could be achieved by a 50 percent reduction in gas oil surface tension. Fundamental theoretical work is the basis of our understanding.

3. Miscible displacement in fractured porous media is much more efficient than the general belief based on current literature models. The crossflow between the matrix and fracture is very pronounced. Our experimental and theoretical work support this conclusion.

4. In solution gas-drive, the formation of a new gas phase below the bubblepoint pressure is an instantaneous nucleation process. We have established this point both theoretically and experimentally. The nature of gas phase evolution has revealed that in fractured light oil reservoirs, solution gas-drive is not efficient, whereas in fractured heavy oil reservoirs solution-gas driven might be very efficient.

5. A numerical model which incorporates the concepts of capillary continuity and reinfiltration has been developed.

6. Experimental results have revealed that capillary imbibition could lead to efficient displacement of oil by water in tight matrix blocks with a permeability of less than 0.01 md.

7. Water injection in fractured porous media is affected by fracture intensity. The higher the fracture intensity, the higher the recovery performance would be.

Some thirty-five papers (mostly SPE publications) have been written from the work of this research program.

PROJECT FACT SHEET

CONTRACT TITLE: Fractured Petroleum Reservoirs

ID NUMBER: DE-FG22-96BC14850

B & R CODE: AC1005000

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CONTRACT PERFORMANCE PERIOD:
03/14/1996 to 03/13/1999

PROGRAM: Supporting Research
RESEARCH AREA: Extraction Research

OBJECTIVE: The main objectives of this project are to develop a full understanding of the role of diffusive, capillary, gravity and viscous forces in the flow of fluids in fractured porous media. The plan is to conduct a comprehensive experimental and theoretical research program to better understand the basic mechanisms of oil recovery and recovery enhancement of fractured petroleum reservoirs.

METRICS/PERFORMANCE:
Products developed:

PROJECT DESCRIPTION:

Background:

Work to be performed: This project is comprised of four major tasks: 1) Fracture Capillary Pressure and Relative Permeability. 2) New Phase Formation and Flow in Porous Media. 3) Water Injection in Fractured and Layered Porous Media. 4) Fracture Reservoir Characterization from PVT data.

PROJECT STATUS:

Current Work: Three of the four major tasks were very active in the first year of the program.

Task II - New Phase Formation and Flow in Porous Media - We studied the formation of 1) a new liquid phase applicable to gas condensate reservoirs, and 2) a new gas phase applicable to cold production of heavy oil reservoirs. The work on liquid phase formation is of a theoretical nature while the work on gas phase formation is an experimental study at this stage.

On the new liquid phase formation, we developed a phenomenological model for the study of critical condensate saturation. This model is based on the formation of new liquid phase in the small capillary tubes of the network, and growth of the liquid phase through stability analysis. The model shows that the critical condensate saturation is a function of 1) interfacial tension, 2) contact angle hysteresis, and 3) pore geometry.

We are currently studying gas phase mobility. Gas phase mobility is the most important parameter of well deliverability. An SPE paper on critical condensate saturation was presented at the 1996 SPE Annual meeting.

The study of new gas phase formation is carried mainly in the context of solution gas drive in heavy oil reservoirs. We have designed and built a new visual high pressure coreholder for this subtask. A heavy oil from California is currently under study. We are preparing an invited paper for presentation at the 1997 Annual meeting of CIM in Canada. The work in Task II is on schedule.

Task III - Water Injection in Fractured and Layered Porous Media - Our efforts on this task were mainly directed towards the study of water injection in water-wet fractured media.

In a theoretical study we modeled the displacement efficiency of co-current and counter-current imbibition. Based on this work, we concluded that the co-current process is much more efficient than the counter-current process. A paper was submitted to the SPE Journal. In this paper, we discuss details of our findings on the merits of co-current imbibition.

In a parallel experimental work, the nature of imbibition in fractured media was studied; Kansas outcrop chalk was used in the experimental work. The observations from the experimental work are: 1) imbibition in fractured media is mainly of co-current imbibition, and 2) co-current imbibition is more efficient than counter-current imbibition. The experimental work supports the theoretical analysis. An important consequence of the work is that the current method of immersing an oil-saturated block in water in the laboratory gives a pessimistic picture of water injection in fractured reservoirs.

In the next phase, we plan to study water injection in oil-wet and mixed-wet media.

Task IV - Fractured Reservoir Characterization from PVT Data - There are four basic mechanisms that affect fluid distribution in hydrocarbon reservoirs 1) molecular diffusion, 2) thermal diffusion, 3) pressure diffusion, and 4) thermal convection. The coupling between thermal convection and diffusion processes have not been done in the literature. In the first part, we have used a binary mixture of two hydrocarbons to study composition variation in a model system. The results show that with convection, it is possible to have more segregation and separation. We have yet to explain this surprising result in simple terms.

The results are also very sensitive to thermal diffusion coefficients. Current models of thermal diffusion coefficients are very unreliable. In the next step, we plan to work on developing a model for the estimation of thermal diffusion coefficients. Then we may try to model fluid distribution in a fractured reservoir for a binary mixture.

Scheduled Milestones:

Accomplishments:

PROJECT FACT SHEET

CONTRACT TITLE: Fractures and Stresses in Bone Spring Sandstones (PARTNERSHIP)

ID NUMBER: FEW 2266.100

B & R CODE: AC1510100

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CONTRACT PERFORMANCE PERIOD:
01/01/1989 to 06/30/1992

PROGRAM: Lt Oil
RESEARCH AREA: Partnership/Oil Recovery Technology

OBJECTIVE: To determine if natural fractures exist in, and affect production from, the Second Sandstone of the Bone Spring formation, Delaware Basin, SE New Mexico.

METRICS/PERFORMANCE:
Products developed:

PROJECT DESCRIPTION:

Background: The Second Sandstone of the Permian-Age Bone Spring Formation in the Delaware Basin of SE New Mexico is a thick, low permeability, light oil reservoir which contains an estimated 35 million barrels per section. Current development indicates the effective drainage of each well is on the order of 5 acres and less than 4% of the original-oil-in-place is being recovered. The reason for this poor performance is believed to be reservoir heterogeneity. The Second Sandstone has been viewed as naturally fractured, primarily because the overlying dolomite stratum is fractured. However, there is no direct evidence for fractures in very limited core and log data, and two orthogonal horizontal wells did not improve production. It was at this point that Harvey E. Yates Company, Roswell, NM, approached Sandia National Labs for possible help. Sandia has specific technology which focused on various aspects of geology and sedimentology, geomechanics, core and log analysis, stimulation, and has resulted in a unique perspective on natural fractures and in-situ stresses.

Work to be performed: This was one of the first two projects with independents conducted under the auspices of the Oil Recovery Technology Partnership. This project sought improved recovery from low permeability, possibly naturally fractured, light oil reservoirs in the Second Sandstone of the Bone Spring formation which are a significant resource in the Delaware Basin of SE New Mexico, but which historically have had very limited production (5 acres and 4% recovery). SNL worked jointly with the Harvey E. Yates Company (Heyco), Roswell, NM, to apply specific technologies obtained from the Multiwell Experiment and other SNL programs in the areas of sedimentology, natural fracture systems, geomechanics, stimulation, drilling and diagnostic instrumentation to enhance production from these reservoirs.

PROJECT STATUS:

Current Work: Activities with Heyco completed. Final documentation complete.

Scheduled Milestones:

AJ11 Federal No. 1 and Cal-mon 15 state No. 1 wells	06/89
Can Ken 4 Federal No. 2 well	02/90
Young Deep No. 26 & No. 27 wells	08/90
Complete data analysis with industry partner (Heyco)	08/91
Complete final documentations	06/92

Accomplishments: Sandia conducted detailed core, log, geologic, stress and well test activities on three Heyco development wells between 4/89 and 5/90. In addition, Sandia assisted Heyco as they applied similar efforts to two development wells in Fall 1990. Contrary to expectations, no natural fractures were found in either core or logs in Bone Spring sandstones. Yet well test permeabilities were 20-30 d, compared to 1 d for matrix rocks, indicating a marginal fracture system may yet exist. Results suggest the wells are poorly connected to the reservoir and that formation damage is important. Natural fractures found in underlying or overlying strata were parallel to the stress field, suggesting that hydraulic fractures may not intersect them. No stress barriers were found, so hydraulic fractures are expected to extend out of zone, thus reducing their effectiveness. Analysis of pressure decline behavior after a minifrac suggests there are no serious leakoff problems, but even minimal leakoff into the marginal natural fractures may cause damage. Results confirm the reservoir is complex with several interrelated mechanisms affecting production. FY89 results published as a comprehensive report on Sandia's work in the project, (SAND90-2068) 'Fractures and Stresses in Bone Spring Sandstones'. FY90 results were contained in the overall final report for the project (SAND92-0359) "Fractures and Stresses in Bone Spring Sandstones: Final Report" which was published June 1992.

PROJECT FACT SHEET

CONTRACT TITLE: Geomechanics of Horizontally Drilled, Stress-Sensitive, Naturally Fractured Reservoirs (PARTNERSHIP)

ID NUMBER: FEW 2836.400

B & R CODE: AC0530000

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CONTRACT PERFORMANCE PERIOD:
06/23/1991 to 09/30/1993

PROGRAM: Supporting Research
RESEARCH AREA: Partnership/Oil Recovery Technology

OBJECTIVE: To determine the effects of rock properties, in situ stresses, and changes in effective stress on the performance of horizontal wells in stress-sensitive, naturally fractured reservoirs of interest to the U.S. petroleum industry.

METRICS/PERFORMANCE:
Products developed:

PROJECT DESCRIPTION:

Background: In situ stresses and changes in effective stress during reservoir production affect the mechanical and fluid flow behavior of a naturally fractured reservoir. Understanding these effects is important in a multi-disciplinary approach to reservoir characterization, drilling and completions, and reservoir management for optimum production. Despite increased use of horizontal drilling as a means of producing fractured reservoirs, relatively few studies have been undertaken to understand and quantify these effects. This project utilized Sandia's established geomechanics capabilities and Orxy's leadership position and experience in horizontal completions to attack this important problem.

Work to be performed: This cooperative project between Oryx and Sandia investigated the effects of rock properties, in situ stresses, and change in effective stress on the deformation and permeability of stress-sensitive, naturally fractured reservoirs. The initial focus was the Austin Chalk, but the study also considered the Bakken shale and other reservoirs of interest. The project has an integrated geomechanics approach involving field work, laboratory studies, and the development of experimental test techniques and analytical models.

Tasks included:

1) Characterization of the natural fracture system.
2) Studies of deformation and permeability of fractures under in situ conditions.
3) Measurement of intact rock (matrix) properties.
4) Analysis of the reservoir's stress path resulting from changes in pore pressure caused by production.
5) Documentation of results as appropriate throughout project.

PROJECT STATUS:

Current Work: Austin Chalk activities have been documented to conclude project. Its reference is: "Geomechanics of Horizontally-Drilled, Stress-Sensitive, Naturally-Fractured Reservoirs" by David J. Holcomb, Stephen R. Brown, John C. Lorenz, William A. Olsson, Lawrence W. Teufel, and Norman R. Warpinski. Sandia National Laboratories Report SAND 94-1743, 51 pages, September 1994. The Bakken or another shale was not studied due to shift in the industrial partners' focus and difficulties in testing shale.

Scheduled Milestones:

Select samples for laboratory experiments	07/91
Begin permeability measurements under stress	08/91
Conduct prototype permeability experiments under shear	10/91
Collect fracture and production data for correlation	12/91
Characterize natural fracture systems of interest	02/92
Complete permeability measurements under stress	09/92
Complete surface roughness studies & tie to permeability	09/92
Determine reservoir stress paths & correlate w/performance	09/92
Complete documentation of Austin Chalk results	12/92
Publish final report	09/94

Accomplishments: Project was initiated at a kick-off meeting 07/16/91; comprehensive project review meetings with Oryx held 12/17/91 and 07/20/92. Significant results were obtained for Austin Chalk in 5 areas: (1) natural fracture distributions determined and unique saddle-shaped induced fractures related to stresses; (2) alpha in the effective stress law found to be 0.4 - much lower than believed - indicating higher effective stress on fractures; (3) unique experiment measured permeability of natural fractures under shear conditions; (4) fracture surfaces and apertures profiled - like other rocks and Gaussian aperture distribution; (5) true triaxial tests show strong effect of intermediate stress - increased strengths and more ductile behavior, but (6) Oryx field data were found to be insufficient to derive the reservoirs stress path during past production.

PROJECT FACT SHEET

CONTRACT TITLE: Geomechanics for Reservoir Management

ID NUMBER: FEW 4365

B & R CODE: AC1005000

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CONTRACT PERFORMANCE PERIOD:
10/01/1991 to 09/30/1998

PROGRAM: Supporting Research
RESEARCH AREA: Rsvr Characterization

OBJECTIVE: The objective of this work is to develop improved understanding and tools for the management of reservoirs. The geomechanics approach to the characterization, stimulation, and production of oil reservoirs involves the characterization of natural fracture systems, the measurement of in situ stress, an understanding of the evolution of stress state with reservoir production, and the determination of the mechanical and transport properties of reservoir rocks and fracture systems and how those properties change with the evolving stress state.

METRICS/PERFORMANCE:
Products developed:

PROJECT DESCRIPTION:

Background: Reservoirs are dynamic systems that are constantly changing during their production history. Primary hydrocarbon production of a reservoir will reduce the pore pressure, increase the effective stresses and alter the formation permeability and fracture flow characteristics. Major steps for improving reservoir management requires the characterization of reservoir fracture networks, meaningful mechanical property and permeability data that are obtained under realistic reservoir conditions, and improved capability to integrate coupled mechanical-fluid flow effects into reservoir production models.

Work to be performed: Cost-effective improvements in the technology to develop and manage reservoirs in difficult and complex environments require a better understanding of how the mechanical and fluid-flow behavior of reservoirs evolve with production-induced changes in effective stress state. This is particularly true in high-porosity, weak reservoir rock and naturally fractured reservoirs, because deformation and the coupled fluid-flow behavior are highly stress sensitive. The overall objectives of this project are to develop a more complete understanding of these coupled processes through an integrated geomechanics effort involving field activities, laboratory investigations, and numerical model simulations; and to apply this approach to selected reservoirs.

PROJECT STATUS:

Current Work: Efforts have focused on five areas of investigation: (1) the description and quantitative analysis of fracture systems and their relationship to lithology and regional tectonic setting; (2) determination of the influence of in situ stress on fracture conductivity and strength; (3) measurements of matrix rock properties as a function of stress and in situ stress history; (4) development of numerical models to simulate coupled fluid flow - mechanical deformation and application of these methods to the analysis of reservoir problems; and (5) development of advanced laboratory capabilities to simulate reservoir conditions and characterize the response of reservoir rocks.

Scheduled Milestones:

Technical status report concerning fracture network analysis
Technical report concerning advanced, true-triaxial geomechanics testing facility
Technical report concerning discrete element modeling of sandstone properties and sensitivity study of fluid-sandstone interactions leading to sand production

Accomplishments: Fracture analysis is being conducted at several field sites including the Spraberry formation (Texas), the Salt Valley Anticline (Utah), the Lucero Uplift (New Mexico), and the Teapot Dome (Wyoming) along with efforts to relate fracture distribution to mechanical properties and in situ stresses. Ultimately, the fracture characterizations will be correlated with in situ stress data to provide predictive models for reservoir characteristics for exploration and for application to optimization of production. In situ stress data for Spraberry are being developed by conducting velocity-anisotropy tests in the laboratory on several samples. The results of these tests will provide stress orientations, and possibly an estimate of stress difference at this location.

New laboratory capabilities have made it possible to study the mechanical and transport response of reservoir rocks under a wide range of stress paths and true three-dimensional stress states. This capability allows for testing at high hydrostatic starting pressures, elevated pore pressures, and with complete 3D strain measurements. An extensive suite of tests has been completed on Castlegate sandstone to fully characterize its behavior under three-dimensional stress states, representative of in situ stresses. Tests included hydrostatic loading tests and a variety of conventional and true 3D load paths suitable for determining the complete stress envelops that govern shear failure and pore collapse. Future work will include similar work on Austin chalk formations and other producing reservoir rocks.

Development of new capabilities includes methods for the characterization of the microscopic structure and transport properties of porous materials. These methods are needed to generalize and extrapolate laboratory transport properties. Products of these approaches will support the discrete element developments and predictions of the influence of changes in the effective stress, especially in 3D.

Mechanical and transport properties of weak, high porosity rock are of critical importance in the development of consistent models of reservoir behavior. Frustrating a comprehensive understanding of these materials are the inherent restrictions associated with microscale experimental procedures used in their characterization. It is exactly at these scales that non-linear behavior, pervasive in reservoir materials, is considered to arise. To compliment and enhance experimental investigation, a set of numerical techniques known as Discrete Element Methods (DEM) are being utilized to model geomaterials at the microscale.

PROJECT FACT SHEET

CONTRACT TITLE: Enhanced Oil Recovery Utilizing High-Angle Wells in the Frontier Formation, Badger Basin Field, Park County, Wyoming -- Class I

ID NUMBER: DE-FC22-93BC14950

B & R CODE: AC1010000

CONTRACT PERFORMANCE PERIOD:
10/21/1992 to 12/31/1994

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PROJECT SITE

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CITY: Park Co.	**STATE:**
CITY:	**STATE:**

OBJECTIVE: This study of the Frontier Formation in Badger Basin Field, Park County, Wyoming, will use 3-D seismic and core data to analyze the diagenetic history, rock properties, and the natural fracture system. It is expected that this approach will be the basis for increasing recovery using slant and horizontal wells to intersect oil-bearing fractures.

METRICS/PERFORMANCE:
Products developed:
Noteworthy Technological Successes:
Incremental Production from Project:
Application of Results:

TECHNOLOGIES USED: 3-D seismic, core analysis

PROJECT DESCRIPTION:

Background: Badger Basin Field was discovered in 1931 by drilling a surface structure. To date only 15% of the 25 million barrels of original oil in place has been produced from this fractured reservoir. The field is not under any pressure maintenance system at this time, although water and gas have been injected into the field in the past. Almost 40% of field production has come from one of the twenty field wells. The low and variable recovery points to both compartmentalization (common to fluvial dominated deltaic systems) and fracturing. These production problems are common in other Wyoming fields.

Unique/Novel Aspects:

Expected Benefits/Applications:

Work to be performed: The objective of this project at Badger Basin Field, Park County, Wyoming, is to increase the recoverable reserves through an integrated approach using geological, geophysical, and engineering methods. The project will use 3-D seismic and core data to analyze the rock properties, and the natural fracture system. In addition to the seismic study, the spacing and orientation of the fracture systems will be analyzed in a new slant well. These analyses will be used to design a horizontal well, which will validate the fracture characterization studies. It is expected that this approach will increase recovery by intersecting the maximum number of oil-bearing fractures. The Frontier reservoir is located at a depth of approximately 8000' in this field. To enhance technology transfer, industry personnel will be encouraged to tour the project facility and review all project data.

PROJECT STATUS:

Current Work: Project completed; in closeout status. In the first quarter of 1994, Badger Basin field was sold to The Run Companies, although Sierra Energy has retained the right to conduct this project. Based on discussions with Run, additional seismic interpretation is being conducted, as a basis for selecting the proposed slant and horizontal well locations. The project has been delayed by the sale of the field.

Problems and Resolutions: Project terminated.

Accomplishments: Core and thin section analysis has been completed and well log and production data has been interpreted to define the directional heterogeneity and its relation to natural fracture systems. A 17 square-mile 3-D seismic survey has been acquired and processed and interpretation has been completed. Well location has been selected based on the reservoir strides.

Recent Publications: Walker, J.P. and R. G. Fortmann, 1994. Enhanced Oil Recovery Utilizing High-angle wells in the Frontier Formation, Badger Basin Field, Park County, Wyoming: Annual Report, Bartlesville Project Office, U.S. Department of Energy, Bartlesville, Oklahoma.

Ongoing/Future Work:

Recent/Upcoming Technology Transfer Events:

PROJECT FACT SHEET

CONTRACT TITLE: Scale-Up of Miscible Processes for Heterogeneous Reservoirs

ID NUMBER: DE-FG22-92BC14852

B & R CODE: AC1005000

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CONTRACT PERFORMANCE PERIOD:
09/30/1992 to 01/31/1996

PROGRAM: Supporting Research
RESEARCH AREA: Extraction Research

OBJECTIVE: To demonstrate how miscible flood processes can be applied to heterogeneous reservoirs.

METRICS/PERFORMANCE:

Products developed: (1) Developed a new streamline simulation technique that is orders of magnitude faster than conventional simulation and is not adversely affected by numerical dispersion. (2) Developed a rigorous procedure for calculation of minimum miscibility pressure in multi-component systems. (3) Demonstrated that viscous fingering, heterogeneity, and gravity segregation interact strongly, and that three-dimensional flow in a reservoir can differ substantially from a two-dimensional model prediction. (4) Obtained quantitative scaling estimates for transitions from capillary-dominated to gravity-dominated to viscous-dominated flows. (5) Demonstrated experimentally that high pressure CO2 can be used to recover oil from fractured reservoirs.

PROJECT DESCRIPTION:

Background: Of the available suite of advanced oil recovery methods, gas injection presently has the greatest potential for additional oil recovery from U.S. light oil reservoirs. Miscible flooding processes have generally been applied in reservoirs that are not too heterogeneous. The low viscosity of the injected gas insures that it will flow rapidly in high permeability zones or fractures. The aim of this project is to extend the range of reservoirs to which miscible gas injection can be applied successfully.

Efficient application of miscible floods to heterogeneous reservoirs requires the designer to take advantage of more than one of the physical mechanisms that act and interact to determine displacement performance. This research effort is directed toward how the interactions of phase behavior, nonuniform flow, and crossflow offer design opportunities for applications of gas injection to near-miscible recovery processes, to enhance gravity drainage, and to fractured reservoirs.

Work to be performed: A comprehensive research program is underway to develop design techniques for "miscible" and near-miscible gas injection processes in heterogeneous fluvial deltaic (class 1) and carbonate (class 2) reservoirs. The key idea is to use high permeability flow paths (which may be layers or even fractures) to deliver injected solvent (CO_2, methane, nitrogen or enriched gas) to lower permeability zones. Crossflow, controlled by gravity, viscous, and capillary forces is the mechanism that moves solvent high permeability regions into lower permeability zones of the reservoir.

PROJECT STATUS:

Current Work: Project is on schedule.

Scheduled Milestones:

Project initiated	09/92
Annual Review Meeting	05/95
Multicomponent miscibility	06/95
Flow Visualization Experiments	08/95
Simulations of Experiments	08/95
Annual Report	10/95

Accomplishments: The Annual Review Meeting for 1995 was held on May 9, 1995 at Stanford. Twelve industrial sponsors (Eight domestic and four international) funded the research program along with the Department of Energy. The meeting was attended by sixteen representatives. Presentations by students and staff working with Professors Orr, Fayers, and Blunt focused on (1) the role compositional effects in the development of miscibility including analysis of minimum miscibility pressure (MMP) behavior in N_2/CH_4, systems an analytical method for calculating MMP's, and an analysis of rising bubble experiments, (2) gravity drainage in gas/oil systems, including experimental results for a CO_2/crude oil system, and a review of gas injection experience in fractured reservoirs, (3) three-phase flow, including analyses of the mathematics of three-phase flow and three-phase gravity drainage and pore-level modeling of three-phase flow, (4) macroscopic models of viscous fingering, and (5) streamtube/streamline methods to model efficiently the interplay of compositional mechanisms with flow in heterogeneous reservoirs. The objective is to build a quantitative picture of how mechanisms that act at relatively large scales (such as gravity segregation, heterogeneity, viscous fingering) interact with those that operate at the scale of pores and clusters of pores (such as phase equilibria, three-phase relative permeability, capillary and viscous crossflow, etc.) From that physics-based picture, rational designs of processes for heterogeneous reservoirs can proceed.

PROJECT FACT SHEET

CONTRACT TITLE: Prediction of Gas Injection Performance for Heterogeneous Reservoir

ID NUMBER: DE-FG22-96BC14851

B & R CODE: AC1005000

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DOE PROJECT MANAGER:
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LOCATION: NPTO
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PROJECT SITE
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CITY: **STATE:**
CITY: **STATE:**

CONTRACTOR: Stanford University
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CONTRACT PERFORMANCE PERIOD:
09/30/1996 to 09/29/1999

PROGRAM: Supporting Research
RESEARCH AREA: Extraction Research

OBJECTIVE: To demonstrate how gas injection can be applied to heterogeneous reservoirs.

METRICS/PERFORMANCE:
Products developed:

PROJECT DESCRIPTION:

Background: Of the available suite of advanced oil recovery methods, gas injection presently has the greatest potential for additional oil recovery from US light oil reservoirs. Gas injection, particularly misicble or near-miscible flooding, have hitherto been applied to relatively homogeneous reservoirs. The low viscosity of the injected gas ensures that it will flow rapidly through high permeability zones and fractures. The aim of this project is to extend the range of reservoirs for which gas injection may be applied successfully.

Efficient application of gas injection to heterogeneous reservoirs requires the engineer to take advantage of the physical mechanisms that interact to determine oil recovery. This research is a study of these mechanisms, namely phase behavior, nonuniform flow, and crossflow, which offer opportunities for applications of gas injection to near-miscible recovery processes, gravity drainage and recovery from fractured reservoirs.

Work to be performed: A comprehensive research program is underway to develop design techniques for gas injection in a variety of different reservoir types. The key idea is to use high permeability flow paths (which may be layers or fractures) to deliver the injected gas (CO2, methane, nitrogen or reservoir gas) to lower permeability zones. Crossflow, controlled by gravity, viscous and capillary forces, is the mechanism that moves the gas from high to low permeability regions, thus increasing recovery.

PROJECT STATUS:

Current Work: Work is concentrating on three main areas. (1) The use of a pore level model to predict transport parameters for three phase flow. (2) The development of a fast reservoir simulator to predict oil recovery during gas injection. (3) Experiments to determine three phase relative permeability and oil recovery for different fluid systems and rock types.

Scheduled Milestones:

The completion of gravity drainage experiments using the CT scanner that measure three phase relative permeabilities

Prediction of experimental three phase relative permeability using network modeling

Incorporation of multiphase flow with gravity and compositional effects in a three dimensional streamline model

Accomplishments: (1) The development and testing of a fast reservoir simulator based on streamlines. (2) The formulation of a methodology for the calculation of mimimum miscibility pressure for gas injection. (3) The use of a pore level model to compute three phase relative permeability.

PROJECT FACT SHEET

CONTRACT TITLE: Advanced Recovery Concepts - In Situ Permeability Modification using Gelled Polymer Systems

ID NUMBER: G4S60331	**CONTRACTOR:** University of Kansas Center for Research, Inc.
B & R CODE: 95-A03	**ADDR:** 2291 Irving Hill Road
CONTRACT PERFORMANCE PERIOD: 07/15/1996 to 10/31/1998	Lawrence, KS 66045
	PRINCIPAL INVESTIGATOR:
	NAME: Don Green
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DOE PROJECT MANAGER:	**FAX:**
NAME: Jerry F. Casteel	**INTERNET ADDRESS:**
LOCATION: BDM	
PHONE: (918) 699-2045	**PROJECT SITE**
	CITY: Lawrence **STATE:** KS
	CITY: **STATE:**
	CITY: **STATE:**

OBJECTIVE: To develop and improve the application of gelled polymer technology for in situ permeability modification.

METRICS/PERFORMANCE:

Products developed: Produce and evaluate gel systems that block fractures and/or high permeability zones to improve volumetric sweep efficiency for water or chemical flooding or reduce water influx in production wells.

Noteworthy Technological Successes:

Incremental Production from Project:

Application of Results:

TECHNOLOGIES USED:

PROJECT DESCRIPTION:

Background: Volumetric sweep efficiency is often poor when waterfloods or other displacement processes are conducted in layered or fractured reservoirs. Diversion of fluids into poorly swept or unswept zones can improve oil-water production ratios and extend the life of many domestic reservoirs. In production wells water influx is a common problem resulting in high water-oil rations and possible water disposal problems. Gelled polymer treatments for in situ permeability modification have achieved some commercial success. However, product development for some reservoir types and applications are still urgently needed. These areas that will be addressed in this project include 1) gel treatments in fractured systems, 2) gel treatment in carbonate rocks, 3) in-depth placement of gel systems, 4) gel treatment in carbon dioxide miscible displacement, and 5) gel treatment of production wells.

Unique/Novel Aspects:

Expected Benefits/Applications:

Work to be performed: Task 1. Study of Gel Performance in Fractures. Preliminary experiments were conducted in a physical model of a fractured porous medium to calibrate the flow of a viscous fluid flowing in the fracture. This research is directed toward finding cost-effective gellable fluids that can be applied in fractured reservoirs to plug fracture systems that may be high-permeability conduits for water in waterfloods or for encroachment of bottom water.

Task 2. Study of Gel Performance in Carbonate Rocks. Fluid flow through Baker dolomite core was studied as a function of pH, flow rate, injected volume, and residence time, to determine dissolution/reprecipitation within the core.

Task 4. Develop Gel Systems for Application with CO2. Previous research had indicated good permeability reduction was achieved in Berea sandstone cores with sulfomethylated resorcinol-formaldehyde gel systems in a brine/CO2 environment. Permeability to brine and super critical CO2 were determined in a heterogeneous radial core. The core will be treated with the above gel system and allowed to gel; then, the permeability will be remeasured.

Task 5. Gel Treatments in Production Wells. Flow experiments in a Berea sandstone slab were conducted to determine relative permeability to oil and water. Imbibition and drainage curves were measured on a similar core to determine the extent of water wettability. In-situ fluid saturation were measured on the Berea slab. The core will be treated with a polyacrylamide-chromium gel system. Post-treatment relative permeability to oil and water will be determined.

PROJECT STATUS:

Current Work: The contract has just been negotiated and work is scheduled to begin in the second half of 1996.

Problems and Resolutions:

Accomplishments: Work has just been initiated.

Recent Publications:

Ongoing/Future Work:

Recent/Upcoming Technology Transfer Events:

PROJECT FACT SHEET

CONTRACT TITLE: Modification of Chemical and Physical Factors in Steamfloods to Increase Heavy Oil Recovery

ID NUMBER: DE-FG22-96BC14994/SUB

B & R CODE: AC1005000

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PROJECT SITE
CITY: Los Angeles **STATE:** CA
CITY: **STATE:**
CITY: **STATE:**

CONTRACTOR: Univ. of So. California

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CONTRACT PERFORMANCE PERIOD:
08/26/1996 to 08/25/1999

PROGRAM: Supporting Research
RESEARCH AREA: Extraction Research

OBJECTIVE: Conduct research directed towards improvement of heavy oil recovery.

METRICS/PERFORMANCE:
Products developed: Major contributions in the supported research in the last three years include: (1) The development of the first-ever pore network simulator describing steam zone growth and steam injection in porous media. (2) The conduct of visualization experiments for a variety of processes involving steam ijection and heavy oil displacement. (3) The development of various techniques for representing reservoir heterogeneity at various scales and their scale-up. (4) The development of predictive models for the enhancement of heavy oil recovery by various methods, including foams. (5) The publication of 14 DOE reports, 36 technical reports and 8 PhD Theses related to the supported research.

PROJECT DESCRIPTION:

Background: The original subcontract from SUPRI with L. Handy as the Principal Investigator was awarded to the Department of Petroleum Engineering at USC for the period May 1, 1987 through September 30, 1988 (FY87-FY88) for $150,000. The subcontract was renewed for an additional year, Oct. 1, 1988 through September 30, 1989 (FY89) with Y.C. Yortsos as the Principal Investigator for $100,000. An additional subcontract award from SUPRI was awarded for the period Oct. 1,1989 through Feb. 22, 1990 with Y.C. Yortsos as the Principal Investigator for $44,506. Total funding awarded was $294,506 for the period May 1, 1987 through Feb. 22, 1990. Funding for three additional years (Feb. 23, 1990 through Feb. 22, 1993) was awarded through a SUPRI subcontract at the rate of $150 K/yr. In February 1993, a 3-year grant was awarded for $150 K/yr for the period Feb. 8, 1993 through Feb. 7, 1996. In August 1996, a new 3-year grant was awarded to SUPRI with a subcontract to USC for a total of $400 K for the period Aug. 26, 1996 through Aug. 25, 1999.

Work to be performed: To conduct research directed towards improvement of heavy oil recovery.

Project 1. Porous Media Flows with Phase Change- Study of the flows involving steam, water and oil (or other condensable fluids) in porous media with applications to steam injection in the presence or the absence of gravity.

Project 2. Reservoir Heterogeneity- Study of the effect of heterogeneity in reservoir properties at various scales in oil recovery, with particular emphasis in steam injection and heavy oil recovery in fractured systems.

Project 3. Mobility Control Fluids and Process Optimization- Study of the various processes for mobility control (for example foam) and of strategies for process optimization using flow rate control.

PROJECT STATUS:

Current Work: The subcontract proceeds on schedule. One professional (Dr. Y.C. Yortsos, Principal Investigator) and seven graduate students (Youngmin Choi, Chunsan Jia, Persefoni Kechagia, Bagus Sudaryanto, Ioannis Tsimpanogiannis, Lang Zhan, and Yuyong Zhang) work part-time on this research. Fourteen DOE reports, 36 technical reports and 8 PhD Theses have been written related to the supported research in the FY93-96 timeframe.

Scheduled Milestones:

Report on 3-phase flow in porous media	01/97
Report on foam pore-network simulator	02/97
Report on heteorgeneity mapping	04/97
Report on optimization of recovery processes	06/97
Report on pore-network simulation of steam injection in fractured systems	07/97

Accomplishments: Significant accomplishments since the last project fact sheet include: (1) We completed the study of 3-phase flow in a pore network and the computation of three-phase relative permeabilities. A paper is in preparation. (2) Pore-network simulation and experimental visualization of steam injection in fractured media have been conducted. A paper was written on the latter subject and another one is being prepared on the former. (3) Substantial progress was made on the optimization of recovery processes, by developing optimization algorithms using optimal control methods. This work introduces optimal control methods in reservoir management. (4) A paper was written on the representation of viscous effects and on the pore-level origin of Buckley-Leverett displacements in porous media. (5) A paper was written that develops the foundation for understanding foam invasion in porous media for processes of mobility control. (6) We have investigated the effect of gravity override in displacement processes. (7) Substantial progress has also been made to identify the heterogeneity of reservoirs by pressure transients and of laboratory porous media by a novel technique of heterogeneity mapping.

PROJECT FACT SHEET

CONTRACT TITLE: Increased Oil Production and Reserves from Improved Completion Techniques in the Bluebell Field -- Class I

ID NUMBER: DE-FC22-93BC14953

B & R CODE: AC1010000

CONTRACT PERFORMANCE PERIOD:
09/30/1993 to 09/29/1998

DOE PROJECT MANAGER:
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PROJECT SITE
CITY: Roosevelt **STATE:** UT
CITY: Bluebell Field, Duchesne Co **STATE:** UT
CITY: **STATE:**

OBJECTIVE: The project will develop a multidisciplinary reservoir characterization approach to overcoming low petroleum recovery caused by poor completion practices in fractured, clayey reservoirs in the Bluebell field, Uinta Basin, northeast Utah. A well recompletion, a well redrill, and a new well will demonstrate the application of multidisciplinary geological and engineering techniques, such as facies analysis and fracture trend analysis to improve production and increase reserves. The technology transfer plan will include workshops and database distribution.

METRICS/PERFORMANCE:
Products developed: None to date.
Noteworthy Technological Successes: Correlation of major sandstone units and mapping of well data have improved reservoir identification. Regional correlation of fracture patterns has increased understanding of density and direction of major fracture patterns within the Bluebell Field. Use of state-of-the-art borehole-imaging tools has increased the accuracy of lithologic facies identification, fracture identification, and reservoir determination.
Incremental Production from Project: Will be determined during Phase II.
Application of Results: None to date.

TECHNOLOGIES USED: Outcrop analysis, biostratigraphy, well tests, digital database, geostatistics, numerical simulation, borehole imaging logs, recompletion, paraffin control, infill drilling, and hydrojet lance tool.

PROJECT DESCRIPTION:

Background: The Uinta Basin in northeast Utah is the most prolific petroleum province in Utah. Most of the production in the giant Altamont-Bluebell-Cedar Rim fields complex is from multiple, low-matrix-porosity sandstone units that were deposited in lacustrine fluvial-delta systems. The primary problem with completing wells in the Bluebell field is adequately identifying pay zones in the thick, heterogeneous sequence. As a result, existing well completions suffer from thief zones, unperforated oil-bearing zones, and inefficient placement of chemical treatments.

Unique/Novel Aspects: (1) a very thick pay zone, (2) no interwell correlation of producing horizons, (3) a low matrix reservoir porosity, and (4) nonuniform completion techniques.

Expected Benefits/Applications: Include an accurate determination of pay zones through improved log analysis, improved well completion techniques, and extended overall recovery rate per well and field.

Work to be performed: A multidisciplinary reservoir characterization and three-part demonstration program is being used to overcome low productivity caused by poor completion practices in fractured, clayey reservoirs. The problem of undrained heterogeneous reservoirs will also be addressed. The field wells are frequently perforated through hundreds of feet of gross pay, although only a small portion of the interval may be productive, and thief zones are often open. The demonstration program will involve: (1) a recompletion (Michelle Ute well) of a large interval, (2) isolation and recompletion of several narrow intervals in a well near the Michelle Ute well, and (3) drilling and completing a new well.

PROJECT STATUS:

Current Work: The geologic evaluation of a 20 square-mile area within the Bluebell field was used to determine the thickness and lateral distribution of nearly 40 beds which were subsequently used in the computer modeling analysis. The computer modeling analysis was used to determine the volume of original fluids in place (oil, gas, and water) for each of about 40 individual beds. The total amount of original oil in place within the 20-square-mile study area is nearly 400 million barrels, only a fraction of which has been produced. Following this, an oil simulation study was completed on five beds thought to contain the most producible oil reserves. This study was used to predict the producibility of oil from wells within the project area and will be compared with currently producing wells. Logs from the Michelle Ute recompletion have been evaluated and correlated with nearby wells. Several zones have been identified for inclusion in the recompletion work for part two and are being designed into that program. Quinex Energy Co. is evaluating the proposal.

Problems and Resolutions: Geological characterization of the reservoir at the bed/facies level has proved to be far more difficult than anticipated. Open-hole and production tests of individual beds are virtually nonexistent. Few of the wells have any production logs to help identify which perforated beds are producing. Data gathering has been adversely affected by a significant drop in drilling activity. Pre- and post-treatment logs will be run to determine which beds are fractured before treatment and which are fractured by the treatment, and which beds are actually contributing to the production.

Accomplishments: The first part of the demonstration program has been completed and work on the second part of the three-part program is in the design stage. The first part of the program involved geophysical logging and re-completion of a large interval of the Michelle Ute 7-1 well. The recompletion included logging the entire production interval, perforating additional beds, and stimulating the entire interval with a three-stage acid treatment. The operator was not able to stimulate the well at high pressure (+10,000 psi) at the three separate packer locations as designed because the pressure would not hold. As a result, the well was treated at a lower pressure (6,500 psi maximum) from one packer location. Following the acid treatment, the well was swab tested and put back into production. The well has been producing at an improved daily rate since the acid treatment. The isotope tracer log that was run after the treatment showed that very few of the perforated beds received acid. The Michelle Ute well was producing an average of 19 barrels of oil per day (BOPD) prior to treatment. After thetreatment, the well produced about 40 BOPD initially, but is currently declining. The increased production is encouraging considering how few beds were actually treated.

Recent Publications: (1) Garner, A., 1996, Outcrop study of the lower Green River Formation for the purpose of reservoir characterization and hydrocarbon production enhancement in the Altamont-Bluebell Field, Uinta Basin, Utah: Brigham Young University, Provo, Utah, M.S. thesis. (2) Wegner, M., 1996, Core analysis and description as an aid to hydrocarbon production enhancement-lower Green River and Wasatch Formations, Bluebell Field, Unita Basin, Utah: Brigham Young University, Provo, Utah, M.S. thesis.

Ongoing/Future Work: The demonstration phase began April 1996. Thickness mapping of individual beds in the study continues. The final reservoir simulation modeling will be completed soon.

Recent/Upcoming Technology Transfer Events: Information booths were staffed at both the Annual and Rocky Mountain Section meetings of the AAPG in 1997. April 1997, AAPG annual meeting Dallas; "Improved Primary Oil Recovery from a (DOE Class 1) Fluvial-Dominated Deltaic Lacustrine Reservoir Unita Basin Utah".